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SATELLITE-TRACKING AND EARTH DYNAMICS RESEARCH PROGRAMS

Grant Number NGR 09-015-002

Semiannual Progress Report No. 46

1 January to 30 June 1982

Prepared for

National Aeronautics and Space Administration
Washington, D.C. 20546

August 1982

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory and the Harvard College Observatory are members of the Center for Astrophysics

The NASA Technical Officer for this grant is Mr. David L. Townley, Code TN-1, Network Operations, Office of Space Tracking and Data Systems, NASA Headquarters, Washington, D.C. 20546.

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SATELLITE TRACKING RESEARCH PROGRAM IN
SOLID-EARTH GEOPHYSICS

Semiannual Progress Report No. 46

1. INTRODUCTION AND SUMMARY

This report describes the activities carried out by the Smithsonian Astrophysical Observatory (SAO) for the National Aeronautics and Space Administration (NASA) under Grant NGR 09-015-002 during the period 1 January to 30 June 1982. Work on geodesy, geophysics and the upper atmosphere are currently funded separately from this grant, although that research is still maintained as part of a total integrated program at the Observatory. Reports related to this are included in Appendix 5.

The SAO laser in Arequipa was in routine operation during most of the reporting period. During the months of March and April, the laser was down for upgrading. In March, the SAO laser operations in Orroral Valley, Australia were closed at NASA's direction. In addition, with the laser upgrading tests completed, SAO closed out the station operation at Mt. Hopkins.

Improvement of the laser system continued as a fundamental part of SAO's tracking program. During this reporting period SAO completed a major laser upgrading program in Arequipa to improve range accuracy and data yield. Modifications were made to the laser and the control system to increase the pulse repetition rate from 8 ppm to 30 ppm. The laser pulse width was reduced from 6 nanoseconds to 3 nanoseconds, and the waveform digitizer was replaced with an analog pulse processor to improve accuracy

and to accommodate the higher pulse repetition rates. Modifications were also made to the photoreceiver to install a narrower band filter, a fast shutter, and a new PMT and base in order to improve signal-to-noise ratio during daylight ranging. Extensive changes were made to the control and prediction software to support this upgrading. With these modifications the laser ranging accuracy is now in the range of 3-5 cm.

The SAO stations obtained a total of 37,099 quick-look range observations on 978 passes in the six months. In addition, routine participation by cooperating networks contributed greatly to the success of ongoing tracking campaigns. Data were acquired from Helwan, Metsahovi, San Fernando, Kootwijk, Wettzell and Grasse.

During the reporting period agreements were concluded between NASA and the CNR in Italy to relocate the SAO laser from Natal, Brazil to a site in Italy. Under these arrangements, the laser is to be set up and operated by the CNR with assistance from SAO. A site has been selected in Matera, Italy and work is now underway to establish the site.

The Network continued to track LAGEOS at highest priority for polar motion and earth rotation studies, and for other geophysical investigations, including crustal dynamics, earth and ocean tides, and the general development of precision orbit determination. The network performed regular tracking of BE-C and Starlette for refined determinations of station coordinates and the earth's gravity field and for studies ot solid earth dynamics.

All production hardware for the upgrading of the other laser units have been built. Testing is currently underway.

Cesium standards and Omega receivers provided on long-term loan by the U.S. Coast Guard continue to function well at the field stations. With these and other timekeeping aids, the laser stations are able to maintain a timing accuracy of better than plus or minus 6 microseconds.

The communications links with Mt. Hopkins, Arizona (through 30 March) and Arequipa, Peru have continued to operate satisfactorily.

Data Services has provided final data to the National Space Science Data Center for the period through May 1982. Final data are now being furnished on a routine basis 60 days after the end of the acquisition month. Most of the software activity was focussed on the adaptation of the field software for the 30ppm modification and the analog pulse processor. Considerable effort was also spent on the prediction software to improve predictions for use with a reduced range gate window.

The minicomputer to VAX link in Cambridge continues to function well. The minicomputers are now routinely used as interactive terminals and as remote data-entry devices. They provide Data Services and other support groups with a remote-batch capability and facilitate the processing of quick-look data.

2. OPERATING STATUS

The SAO laser site in Arequipa continued routine operations throughout the reporting period except for the months of March and April when upgrading was underway. The laser in Orroral Valley was operational through March. Together with the cooperating stations in Wettzell, Grasse, Kootwijk, San Fernando, Helwan and Metsahovi (see Section 3.), the laser stations obtained a total of 37,099 quick-look observations on 978 passes of BE-C, Starlette, and LAGEOS. Monthly statistics of the passes and points, by station and by satellite, are given in Table 1.

Final data statistics for the reporting period for the SAO lasers are shown in Table 2. These data have been sent to the National Space Science Data Center at Goddard Space Flight Center (GSFC).

The skeleton operation at Mt. Hopkins was closed in March after tests for upgrading were completed.

We continue to maintain the operations reporting procedures requested by NASA by providing statistics of tracking success, weather, and maintenance on a monthly basis. Table 3 gives the six-month summary of this information.

Table 1.

Quick-look passes and points, 1 January through 30 June 1982

Station	January Passes	January Points	February Passes	February Points	March Passes	March Points	April Passes	April Points	May Passes	May Points	June Passes	June Points	Total Passes	Total Points
Arequipa	42	800	31	635	55	1,173	18	899	155	11,093	159	9,285	460	23,885
Mt. Hopkins	22	824	29	1,368	2	155							53	2,347
Orroral Valley	25	602	52	1,241									77	1,843
Metsahovi					1	20			3	60			4	80
San Fernando	4	47	3	55	1	64					13	602	21	768
Helwan	9	157	5	96	6	226							20	479
Kootwijk	37	755	35	709	24	451	28	507	11	215	18	360	153	2,997
Wettzell					6	188	27	982	27	848	5	201	65	2,219
Grasse									6	169	29	923	35	1,092
Dodaira	10	99	12	158	21	175	6	77	10	188			59	697
Simosato							22	440	8	235	1	17	31	692
TOTAL	149	3,284	167	4,262	116	2,452	101	2,905	220	12,808	225	11,388	978	37,099

Satellite	January Passes	January Points	February Passes	February Points	March Passes	March Points	April Passes	April Points	May Passes	May Points	June Passes	June Points	Total Passes	Total Points
BE-C	39	828	38	961	32	752	15	337	60	2,910	59	2,610	243	8,398
Starlette	60	1,161	64	1,402	41	700	33	632	64	3,839	94	3,783	356	11,517
LAGEOS	50	1,295	65	1,899	43	1,000	53	1,936	96	6,059	72	4,995	379	17,184
TOTAL	149	3,284	167	4,262	116	2,452	101	2,905	220	12,808	225	11,388	978	37,099

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Table 2.

Final Data Statistics

January-June 1982 Passes/Points

	BE-C		STARLETTE		LAGEOS		TOTAL	
	Passes	Points	Passes	Points	Passes	Points	Passes	Points
Orroral Valley	-	-	23	806	38	1,378	61	2,184
Arequipa	580	2,817	263	3,201	181	12,106	1,024	18,124
Mt. Hopkins	22	826	21	641	11	865	54	2,332
TOTAL	602	3,643	307	4,648	230	14,349	1,139	22,640

* The Orroral Valley station was closed on 31 March 1982.

Table 3.

Laser operations summary, 1 January through 30 June 1982.

Station	Passes scheduled	Passes supported	Data obtained*	Passes cancelled owing to weather**	Passes cancelled owing to system down	Passes cancelled owing to other
Arequipa	988 (100%)	633 (64%)	460 (68%)	312 (32%)	43 (4%)	[illegible] (0%)
Mt. Hopkins	104 (100%)	69 (50%)	55 (72%)	63 (45%)	1 (1%)	7 (5%)
Orroral Valley	371 (100%)	120 (32%)	80 (54%)	225 (60%)	25 (7%)	1 (0%)

* Number of passes and percent of total scheduled minus passes canceled because of weather.

** Not included are passes attempted but unsuccessful because of poor weather.

3. LASER OPERATIONS AT COOPERATING AGENCIES

In addition to operating its own stations, SAO supports the operation of overseas cooperating laser stations by furnishing orbital elements for predictions, screening quick-look data, and acting as a general U.S. interface. These cooperating agencies are located in Greece, Japan, Spain, The Netherlands, France, West Germany, Egypt, Poland, and Finland. During the past six months, SAO actively supported the Centre National d'Etudes Spatiales (CNES) Starlette program with routine laser tracking, providing CNES with orbital elements to sustain its tracking operation.

The laser systems in Dodaira, Japan and Athens, Greece have furnished SAO with data for many years. These data are screened weekly by SAO, and predictions are generated from orbital elements supplied by SAO. Work continues in both lasers to upgrade the systems and overcome technical problems in attempting to reach modes of operation consistent with current program needs. Both systems are operated by local agencies at no cost to NASA. Both have operated as an integral part of the SAO laser tracking network, responding to the routine priorities and schedules arranged by SAO headquarters.

SAO also has close working arrangements with the Institute fur Angewandte Geodasie (IFAG) in the Federal Republic of Germany and the Technische Hogeschool Delft in the Netherlands. The IFAG satellite-ranging system in Wettzell has been tracking LAGEOS and other laser retroreflector satellites with its short-pulse neodymium Yag mode-locked laser system which has consistently demonstrated range-noise performance of 2 to 4 cm. The Technische Hogeschool has an operating laser system at Kootwijk which

is providing tracking data on LAGEOS and other retroreflector satellites with an estimated accuracy of 15 cm.

In addition to the above mentioned stations, the laser at Metsahovi, Finland which is operated by Helsinki University of Technology, Espoo, Finland and the Finnish Geodetic Institute, Helsinki, Finland, has also provided LAGEOS and other satellite tracking data during the past year. The data quality is a bit lower than that in Germany and Holland, but the system in Finland is evolving quite rapidly.

These lasers are providing a significant level of high quality tracking data on LAGEOS and the low orbiting satellites on a routine basis.

SAO has provided these groups with laser pointing-prediction software plus technical support during system development. SAO has also helped coordinate their operational activities and provides orbital elements for predictions and screens their data on a routine basis. It is anticipated that these groups will continue to aggressively support the LAGEOS and Crustal Dynamics Programs.

The close liaison between SAO and CNES continued in FY 1982. During the past year, SAO actively supported the CNES Starlette program with routine laser tracking, as well as provided CNES with orbital elements to sustain its tracking operation. Under a joint cooperative arrangement among SAO, CNES, and the Instituto y Observatorio de Marina, a CNES laser is in routine operation in San Fernando, Spain. This laser furnishes SAO with quick-look data. SAO provides communications and timing services to the laser operation.

From 1977 through 1981, a cooperative laser tracking program with the Soviet Academy of Science, the Technical University of Prague, Czechoslovakia, the Helwan Observatory in Egypt, and SAO was conducted at Helwan, Egypt. For this program, the Soviet Union and the Czechoslovakians provided and maintained a laser tracking system at Helwan, the Helwan Observatory furnished personnel to operate the system, and SAO supplied technical consultation, a station clock, and partial operating support through the Smithsonian Excess Currency program. The data were routinely screened and validated by SAO. Under this program, the station supplied range data at no cost to NASA. In 1980, the system was upgraded on site with a new short-pulse laser, giving an improved range accuracy estimated at 25 cm.

Although the formal program is now over, with Excess Currency no longer available, the program continues on an informal basis.

4. SATELLITE OBSERVING CAMPAIGNS

The laser tracking network continued its program of data acquisition, with particular emphasis on follow-up support for the preliminary MERIT Campaign. In addition, satellite observations were made to:

A. Support the scientific and orbital maintenance requirements for LAGEOS and the Crustal Dynamics Program.

B. Support the study of earth body and ocean tides, seasonal and other variations in the earth's gravity field, and the investigation of polar motion.

C. Provide data for improving the accuracy of station coordinates and the gravity-field model, which are necessary for LAGEOS and other geophysics programs.

D. Support the tracking campaign for Starlette in conjunction with CNES.

With the success of the preliminary MERIT Campaign in 1980, work continues on a routine but informal interim basis to keep continuous tracking coverage on LAGEOS and Starlette and to continue the routine calculation of pole position from all available quick-look data. This is particularly important for all investigations involving long period effects such as the annual and Chandler effects.

5. OPERATIONS AND MAINTENANCE ENGINEERING

The Engineering Group of the Experimental Geophysics Department provides the daily hardware and systems support necessary to maintain routine network operations. It is also responsible for the system modifications and improvements required for new programs.

5.1 Laser and Photoreceiver

All the laser optical components such as laser rods and pockels cells from the closed sites in Natal, Orroral Valley and Mt. Hopkins, have been returned to Cambridge for inspection and refurbishment. A set of components are presently ready for the installation in Matera, Italy. A set of spares is presently being assembled.

During the upgrading in Arequipa the primary mirror of the photoreceiver was cleaned. The secondary mirror had some coating damage and was replaced with the secondary from Mt. Hopkins.

The two laser water cooling units at Mt. Hopkins were modified to include a freeze-up protection circuit. When the Arizona station was closed, these coolers were shipped to Cambridge. These units will be sent to Matera and Arequipa to be used as the laser rod coolers. The units presently at these stations will be used for the flashlamp cooling and as backups. The increased repetition rate of the laser has added strain on the coolers, and made the issue of backup units more critical.

There has been some difficulty with the reliability of thin film polarizers recently purchased from OCLI (California) and Transworld Optics (New York). Tests at Arequipa showed early coating failures. Two off-the-shelf polarizers from a third manufacturer, CVI (New Mexico), were purchased for testing in Arequipa during the upgrade installation. Examination shows no damage after initial testing. These plates will be tested further before a purchase decision is made.

5.2 Data System and Pulse Processor

During the past year many fundamental changes were made to the pulse processing detection systems. These changes are detailed in the upgrading section (See Section 8).

Problems were experienced with the Nanofast counter in Arequipa on a number of occasions this past year. The counter was repaired by the field staff within a few days, with the Eldorado counter used in the interval. However, it appears that there are still some stability problems and a replacement counter will be shipped to the station.

With the closure of the Mt. Hopkins laser station, their data system was returned to Cambridge where it will be set up and used for refinements in the analog processor hardware and as a field hardware set to test the future software improvements. The remaining equipment will stay at Mt. Hopkins in a mothball status.

The station equipment from Natal is in storage at Cambridge. This equipment will be partially upgraded and modified for 50 Hz operation before being sent out to Matera in October.

The equipment in Orroral Valley is being packed up now and will be shipped to Cambridge for storage.

5.3 Minicomputers

An error, first thought to be hardware, occurred both in Arequipa and Natal. The error, finally traced to the lunar perturbation software overlay, was avoided by a change in the epoch of the orbital element. Since this overlay is being re-written, time has not been devoted to correcting this one-time problem.

A problem with the Natal system, which was causing occasional non-fatal single memory cell changes, appears to have been solved by memory module interchange. With the close of the Natal station, the minicomputer was returned to Cambridge for a complete checkout and then sent to Arequipa as a backup unit and a unit for off line processing (generating predictions, processing data, etc.).

The previously reported non-fatal intermittent problem with the Orroral Valley system was becoming more acute. Spare boards were dispatched to update the problem but the station continued to experience difficulties. After the Orroral Valley station was closed, the minicomputer was returned to Cambridge where it is now being overhauled for

shipment to Matera as a backup and an off line processor.

The minicomputer in Arequipa developed a CPU malfunction requiring component replacement on the CPU board. The field staff handled this problem in a routine manner.

For some time, we have had noise problems with the power supplies for the Nova 1200 minicomputers. Parts have been ordered for refurbishment.

All headquarters minicomputers have had their serial I/O interface for the miniterm/decwriter converted from 20 ma current loop to RS232C. Instructions for field conversion were sent to all field stations for implementation.

SAO has been examining options to further enhance the data processing and examination capability in the field. Evaluation tests are underway with a Nova look-alike CPU made by Point 4 Corp. Several Point 4 minicomputers which are much faster than the Data General Nova 1200 minicomputers have been acquired by SAO from U.S. surplus. Several boards and small peripheral items were purchased during this reporting period for these tests. To date, the evaluation indicates that all peripherals can be properly interfaced and all utilities are available. One software driver is yet to be modified to accommodate the faster CPU. Once the system is working well and has passed simulation tests in Cambridge, it will be shipped to Peru for field testing.

5.4 Timekeeping

During this reporting period, timekeeping systems for the SAO tracking network have maintained epoch time traceable to UTC (U.S. Naval Observatory) with an accuracy of better than plus or minus 6 microseconds, except for Egypt, which maintains time to plus or minus 50 microseconds. Each of the NASA supported SAO tracking sites is equipped with a broad-based timing system comprised of dual parallel timing channels. Cesium oscillators, backed up by rubidium oscillators, offer a stable time base for each channel. Redundant time accumulators guard against time discontinuities, and redundant VLF/OMEGA receivers provide a reliable backup and frequency reference for the system. Portable clock comparisons are required to provide the necessary epoch reference checks until another satellite-based time transfer system, such as GPS or Transit, can be implemented.

All laser sites have had portable clock comparisons during the last 12 months with the exception of Egypt. Table 4 summarizes the present estimate of time accuracy and results of clock comparisons.

Table 4

SAO NETWORK TIMEKEEPING STATUS for July,1981 to May,1982

Definitions:

(STAT - UTC) epoch range of SAO field station main clock a positive quantity means station clock ahead of UTC as maintained by the US Naval observatory (USNO)

REDUCTION UNCERTAINTY estimated absolute error of reduced station time during the period specified. Future clock comparisons may lower this uncertainty value.

EPOCH SET UNCERTAINTY estimated epoch time transfer accuracy

LAST COMPARISON the last portable clock comparison on site Cs refers to cesium portable and Xtal to crystal portable

STATION	REDUCTION PERIOD from	thru	(STAT - UTC) RANGE microseconds	REDUCTION UNCERTAINTY <+/-microseconds	EPOCH SET UNCERTAINTY <+/-microseconds	LAST COMPARISON by	when
AUSTRALIA	jul 1 81	feb27 82	2 to 26	1 to 5	1	Bend/Cs	feb 2 82
except	nov 8 81		13	1 sec		Bend/Cs	oct 81
BRAZIL	jul 1 81	aug26 81	9 to 15	4	2	Bend/Cs	sep 2 81
	aug26 81	sep30 81	3 to 4	2	2		
EGYPT	jul 1 81	may 1 82		50		Czech/Cs	81 no data received
MT HOPKINS	dec18 81	dec31 81	5 to 12	4	2	SAO/xtal	dec 81
	jan16 81	mar 9 82	-18to 11	4	2	Bend/Cs	feb 3 81
PERU	jul 1 81	aug21 81	-2 to 18	3 to 5	2	Bend/Cs	aug28 81
	aug21 81	dec31 81	1 to 15	2 to 6	2		
	jan 1 81	may 1 82	15 to 22	5 to 7	2		
except	jul25 81	jul26 81	2 to 12	8			

With the closure of the stations in Natal and Mt. Hopkins, the cesium oscillator and Omega monitor from Natal, and the cesium oscillator from Mt. Hopkins were returned to the United States Coast Guard.

The Omega monitor receiver based at Headquarters was set up to aid in determining signal quality and system reliability for air navigational use at the Department of Transportation (DOT) in Cambridge, Massachusetts. The DOT was interested in studying Omega signal levels and whether the system provided continuous service. A favorable evaluation could mean expanded use of Omega for air traffic navigation. After a defective digital recorder was replaced in January, the system appears to be functioning normally.

An Austron automatic Loran receiver and a linear chart recorder were evaluated for future use in the dual channel timing system.

The first Nova satellite was declared operational and daily timing data as well as data from the earlier Transit system satellites is now being pursued by the U.S. Naval Observatory and referenced to their master clocks. It was a disappointment to learn that the spread spectrum system was not utilized aboard the Nova satellite. Without it, better than a 2 or 3 microsecond accuracy with the system will probably not be possible.

The SAO timing engineer attended the Precise Time and Time Interval Planning Meeting at the Naval Research Laboratory in Washington early in December. He presented a paper entitled "High Accuracy Omega Timekeeping". At the meeting there was much concern about the use of the full GPS capability for civilian applications. Hopefully the issue will be resolved

before a large expenditure in GPS timing receivers is made.

A proposal was written to the Smithsonian Institution Office of Excess Currency (PL 480) to conduct an experiment for obtaining epoch time from Omega transmissions, and maintaining time to an accuracy of about 4 to 6 microsecond for testing a new Austron automatic Loran receiver in a remote location in India. It is in the form of an extension of a current cooperative program, research is to be carried out principally at the Uttar Pradesh State Observatory in Naini Tal, in cooperation with the Smithsonian Astrophysical Observatory, U.S. Coast Guard, and Austron. This work would be carried out as a test of alternative timing systems in remote locations.

6. COMMUNICATIONS

The SAO communications group sends orbital elements to SAO and cooperating field stations and receives quick-look data from the International, NASA and SAO sites.

The communications center provided voice and teletype radio links to the SAO laser field station in Arequipa. SAO also maintains FTS service within the continental United States, and is connected with Western Union, TELEX, NASCOM and RCA GLOBOM circuits for worldwide communications. As a means of economizing, SAO closed out its AUTODIN connection in late FY 1981; requirement for the circuit is now being fulfilled through NASA via NASCOM.

The communications facility was moved to a new area recently and now is in the process of upgrading equipment on all circuits to the more modern ASCII standard. Terminals will be installed with built in storage rather than relying on the paper tape storage as in the past.

The NASCOM circuits are being converted to a single ASCII, 300 baud line to GSFC with model 40 teletype equipment and disk storage to be installed at SAO. This will allow direct interface with our VAX computer and unattended service for longer periods. This upgrading is scheduled to be operational by 15 July.

New equipment is being surveyed which will connect to our telex and TWX lines to allow for ASCII communications with semiconductor storage. The unit should allow direct interface with the VAX computer via high speed data lines or dial up telephone circuits and will have sufficient storage

to allow unattended operation on long weekends.

The HF communication link with Arequipa has been operating satisfactorily during the reporting period.

Studies continue on the feasibility of utilizing a minicomputer-radio link communications path as well as further automation of the Communications path as well as further automation of the Communications Center. These studies are aimed at increasing current system flexibility and reliability as well as accommodating any further expansion.

Using existing equipment we are now testing a radio TTY circuit with ASCII, 300 baud service. Data is being stored on digital cassette recorders and may eventually be sent directly to the Data General Nova 1200 computer.

A test of our present VAX software for interface with the General Electric Mark III computer network was conducted in February. A Nova 1200 minicomputer was interfaced to an Omnitek acoustic modem with a serial interface board. Tests on the system are currently underway and work continues on the software.

In FY 1981, an operational data link between the communications minicomputer and the VAX 11/780 was implemented to facilitate transfer of edited data into the processing files. The minicomputer is now used routinely for data-editing and data-handling aspects of the communications operations, providing considerably greater flexibility and increased speed.

During FY82 SAO reduced its Grant supported communications staff from 2.5 to 2 people in a program-wide effort to reduce costs.

7. DATA SERVICES AND PROGRAMMING

The Data Services Group maintains the operational and prediction cycle necessary for the efficient flow of data to and from the SAO field stations. This group screens and validates all incoming data, generates orbital elements for all satellites being tracked by the SAO laser network and cooperating stations, supplies orbital elements to SAO stations and other agencies, and furnishes SAO laser data to the NSSDC at GSFC.

7.1 Data Services

Two major areas of activity covered by Data Services are the quick-look cycle and final data processing. The quick-look phase functions on a weekly schedule, in which the SAO and cooperating foreign field stations send small subsets of their acquired data through communications channels to Cambridge. These data then form the basis for generating updated orbital elements, which are communicated back to the field stations, where they are used to compute the predictions necessary for laser satellite ranging.

The full data sets on Linc magnetic tape are mailed from the SAO laser stations to Cambridge and sent through the final data-processing cycle. This process consists of an engineering filter to assess data quality, followed by a noise filter, a time correction program and a formatter.

The quick-look functions of the Data Services operation have evolved into a stable, reliable, and smoothly running procedure. Acquisition orbits were computed and transmitted each week virtually without incident. The quality of these orbits remains very high; ephemerides are now routinely computed to the sub-10-meter level and, in the case of LAGEOS, to the 2-meter level.

In the first half of CY 1982, the Data Services group processed 37,099 laser quick-look data points and handled 978 passes from the SAO and cooperating stations on Starlette, BE-C, and LAGEOS. (See Tables 1, 2 and 3).

During the reporting period, the Data Services group, using LAGEOS data from the SAO and NASA laser networks as well as from certain cooperating foreign organizations, provided 5 day mean pole positions as a by-product of the routine orbital determination and data assessment activity. The pole positions are transmitted weekly to the B.I.H. in Paris as a rapid service to the world scientific community.

In CY 1981, the Data Ser 'ces Group processed and sent 82,122 points in 1,856 passes of data to the NSSDC. The Data Services groups has been maintaining a 60 day turnaround on final data submission to the NSSDC. Final data from the SAO laser network from April 1982 were transmitted to the NSSDC by year's end.

SAO compiles and publishes the quick-look data catalog for satellites tracked by the laser systems. The tabulation includes all quick-look data submitted. This catalog also now contains the 5 day mean positions of the

pole. This service has been found useful in the past by members of the scientific community.

As a means of economizing, SAO has re-organized internal procedures in order to carry on operations at a reduced staffing level. The Data Services staff has been reduced from 5 to 2 people. In addition, at the end of the December, the decision was made to stop tracking of two satellites: GEOS-1 (6508901) and GEOS-3 (7502701).

In September 1981, the Observatory took delivery of a second VAX computer. All users, including the Data Services group, have been partitioned between the two machines to balance resources.

Quick-look catalogs for November-December 1980 (Post-Short Merit Campaign Catalog, already published), and CY 1981 are being printed for distribution.

Upgrading of final data processing system is presently underway with the development of 9-track tape capability for the Nova 1200 to replace the current 7 track tape capability.

7.2 Programming Support

SAO maintains a small staff of computer programmers who support the operation of its tracking program. In addition to routine maintenance and upgrading of the minicomputer and production processing programs, the Programming Group develops software to meet new needs and supports the Data Services Group in routine processing as necessary. The Programming Group

analyzes test data for laser-system maintenance and for planning laser-system modifications to improve performance.

7.3 Routine Programming

During FY 82, SAO began the development of field software for data screening. Based on the main frame software currently in use at SAO, the new program uses observed minus predicted residuals as a basis for data evaluation. To date, the program is working on the Nova 1200 computer using a linear screening algorithm, polynomial fitting, and graphic display of residuals. The package is able to handle in excess of 200 data points per fitting segment. The software currently screens data down to the 15-30 cm level. Work is planned to improve the screening capability by using different techniques for the high (LAGEOS) and low satellites. We expect this software to be ready for the field by early FY 83.

In this period, software was developed and tested for generation of IRV's for operational use by the laser network. A prototype version of the package, based on the SAO analytical orbital determinations program "GRIPE" was tested against the University of Texas data in March and was found to be in good agreement. Subsequently, this package has been converted into a production form capable of producing both Texas and GSFC formats at either periodic intervals or at exact pass starts, as required by operations considerations.

In January, testing of Lageos orbit quality as generated by SAO using quick-look data led to the decision to change to a bi-weekly refreshment of ephemerides to replace the weekly cycle used until then. Since that time we have had no adverse experiences with the technique, and tests indicate that the new technique produces more accurate, stable orbits than the old. A modification of the IRV generation software has been developed to test orbital elements against each other. Using this software, a series of longevity tests for prediction orbits for Lageos were performed in May. These comparisons reveal the character of orbital ephemeris degradation for periods up to 112 days. This analysis decomposed the errors into components tangential to the orbit, out-of-plane, and in the rudial direction. The results appear as sinusoids with a period of 1 revolution and whose amplitude, in general, slowly increases with time. Except for the tangential (along-track) component, there is an unsignificant secular rate over this time span. The rudial component sinusoid amplitude increases smoothly from 23m at 28 days to 65m at 112 days. The normal component sinusoid amplitudes increase from 62m at 28 days to 200 m at 112 days. The tangential component (which, in practice is easily compensated for at field sites) secular component is unmeasureable after 28 days but increases to about 160 m after 112 days. The amplitude of the sinusoid of this component increases from 50 m at 28 days to 150 m after 112 days. These results are very exciting because they suggest that the ephemeris generation period could be lengthened to a multiple of the present 2 weeks. Investigations will continue into ways of generating still more accurate and durable orbital elements for LAGEOS, by studying the time series of orbital elements in hopes of understanding how to extrapolate elements more

effectively.

The post-orbit determination bias analysis "De-bias" program was cleaned up to enhance data analysis capabilities. Improvements include 1) automatic polynomial selection, 2) improved display of residuals, 3) improved scaling of histogram of residuals and 4) addition of a chi-squared test for goodness of fit of range residuals to normal distribution.

An operations manual for the Quick-look data catalog program was prepared.

7.4 Programming Support for Upgrading

In support of the laser upgrading program major changes were undertaken in both the field and headquarters software. These include:

Field Prediction Software

1. Accommodate variable operating rates from 8 to 30 ppm.

2. Include narrower range gate window.

3. Add more elaborate lunar-solar perturbation formulations and make other changes and corrections compatible with the orbital program.

4. Develop and implement a more elaborate tracker mount motion model in the sun and zenith evasion routines needed for 30 ppm

__Field Laser Control and Processing Software__

1. Restructure the software to accommodate rates to 30 ppm.

2. Accommodate the analog pulse processor; replace digitizer processing routines.

3. Change field routines for both quick-look and final processing to use data from the Analog processor.

__Headquarters__

1. Modify the Headquarters final data processing to use the data from the analog processor.

7.4.1 Field Prediction Software

In order to use the new range gate capability to improve daylight ranging to LAGEOS it is necessary to upgrade the orbit software and field predictions to the sub-microsecond level (100m).

This involves a two step process, the first to verify compatibility between the orbit program and the prediction program and the second to evaluate and refine prediction quality. During the last year extensive examination and numerical testing were performed on the compatibility between the headquarters orbital routines and the field programs. Problem

areas that were identified included: 1) a small (10m) discrepancy in the Keplerian motion. 2) a 100-200m per week discrepancy in the lunar theory used in the field prediction packages, 3) a 20m problem in the tesseral harmonics, and 4) several other small inconsistencies in coordinate systems and timing.

The problems turned out to be a combination of: (1) inconsistencies in models used in the orbital and prediction programs; (2) inconsistencies in the operating procedures of the two programs, and (3) errors in programming and formulation. A more elaborate lunar-solar perturbation was added to the prediction program. Changes were also made to several other routines within the program and operating procedures were more clearly specified. The latest self consistency checks between the orbit and the prediction programs (zeroset) conducted in May and June show internal consistencies in pointing and range to better than 2 arcsec and 10 meters respectively.

A full test of the LAGEOS prediction software and processing system was carried out during the reporting period. The software was modified as described above. In addition, some orbital parameters were introduced analytically (instead of being solved) and the data fitting period was extended to three weeks. The results obtained are shown in Figure 1. LAGEOS predictions when compared with actual data show an accuracy of better than ±30 meters for a period of 30 days. It appears that more improvement can be derived from a little more care in the calculation of the semi-major axis, or equivalently, the period from historical data if necessary. A more detailed discussion is included in Latimer, et. al.,

1981.

During this reporting period satellite dependent rates and more elaborate tracker mount motion models used in the zenith and sun evasion routines for 30 ppm were implemented.

A preliminary (prototype) version of the prediction program (FLPPS 6.4) was used at Mt. Hopkins to develop some working experience. A minor programming bug in the forecast routine was repaired and a space problem with the predicted return signal strength routine was also solved. In May, 1982, FLPPS 6.4 was fielded to the site at Peru, where no serious problems were found.

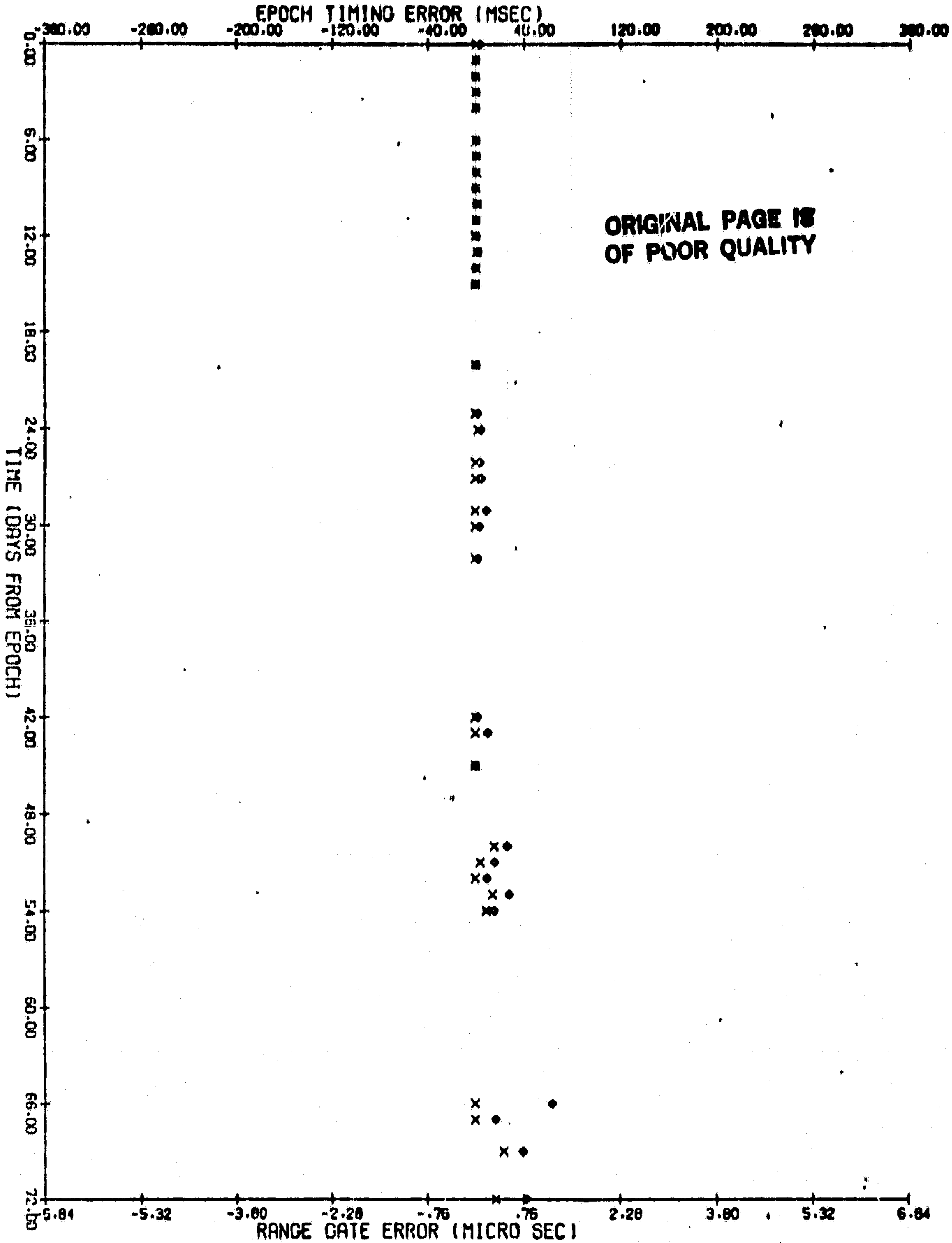

Figure 1.

Estimate of prediction accuracy for LAGEOS using SAO orbit and field prediction software using 18 days of range data. Accuracy is measured in terms of epoch timing error (mean anomaly on the left hand ordinate and prediction range error on the right hand ordinate. Note on this basis one microsecond range error corresponds to 150 m.

7.4.2 Laser Control and Processing Software

In the Laser Control and Processing Software, we have followed a philosophy to ensure us of success at interim stages so that hardware can be tested and software can be fielded as soon as possible. The 30 ppm rate imposes some rather tight constraints that might require major changes in software structure and data handling procedures. The software development procedures were thus following two tracks. The first was to modify the current software, removing as many of the waveform related calculations and digitizer data handling procedures, without changing the overall data output structure (both raw and reduced data tape still provided). This would allow us to gain considerable speed and yet not impact the subsequent processing software. It was anticipated that we would reach 14-20 ppm with these modifications. In parallel we were also developing a new design for the laser control and processing software that would leave only one output tape and would process considerably faster.

On the basis of our experience now however, it appears that we can come very close, and probably reach 30ppm with modifications of the current software. A version of the software has already worked at Mt. Hopkins at 20ppm and several avenues are being pursued in Cambridge to approach the 30ppm rate.

The first approach is to optimize the program code. By converting some of the routines to machine code and improving some of the routine call hierarchies, considerable time can be saved.

The second approach is based on the recognition that every laser shot will not result in a return. However, the software must be able to avoid catastrophic failure if the rate of returns over a short interval is greater than the software capability to process data.

The modifications to gracefully ignore pulses from the laser hardware in the event that the processing falls behind the input has been implemented and tested. (These changes will allow lasing at a rate higher than the throughput, in expectation of a lower rate of successful returns and noise stops). In testing the newly modified software, the Simulator, a program which allows a second Nova minicomputer to simulate the field hardware for testing at headquarters, was found not to transmit the correct framing sequences of control characters around the data lines; this error had not affected the operation of previous versions of Direct Connect, but will cause the system with the latest modifications to fail. The Simulator was changed to correct this problem, and was tested in March.

A third approach is to further reduce some of the complex CRT display and further optimize the I/O to reduce data cycle time.

The latest test version of the Laser Control software which already includes some code optimization and the "graceful failure" facility, is also able to accommodate 100 pre and post-pass target calibrations, instead of the previous 25. This code was tested at Mt. Hopkins in February and was debugged successfully in March.

At present, throughput of this program is about 21 ppm and further areas for speedup have been identified. Field tests at Peru indicate this rate returns over 90% of successful countertops at 30 ppm both for target calibrations and satellite ranging.

Future improvements will be in the method of state changes by operator command, (to avoid waiting for the data to indicate a state change), and bypassing some processing with a failing or missing digitized pulse.

7.4.3 Other Software

The target calibration program was modified to obtain the pulse repetition rate from the satellite ranging records in the intermediate data file rather than from zeroset records. Also, the two digits in the intercoupler previously used for indicating operational parameters for the old pulse processing system will now be used to input the repetition rate for the target calibration program.

The target calibration program was also modified to accommodate 30ppm testing at Mt. Hopkins.

8. DATA QUALITY BEFORE UPGRADING

The Orroral Valley data and the Arequipa data prior to upgrading have an estimated accuracy of 10 cm. This estimate is the r.s.s of measured bias error components within the ranging machine itself.

8.1 Systematic errors

The systematic errors of the laser ranging system can be divided into three categories: spatial, temporal, and intensity (signal-strength) variations. Spatial variations refer to differences in time of flight depending on the position of the target within the laser beam. Temporal variations relate to system drift between prepass calibrations, satellite ranging, and postpass calibration. Range variations due to changes in signal strength are a function of receiver characteristics and digitizer sampling interval.

Typical values for each of these components before upgrading is shown if Figure 2.

Figure 2. Summary of systematic errors before upgrading

Source	High Satellites (cm)
Wavefront distortion (spatial)	4.5
System drift (temporal)	6.0
Calibration (signal strength)	6.0
root sum square (rss)	9.6

These are the systematic errors that can be expected for data averaged over a pass before upgrading. In addition, errors in timing, refraction, and spacecraft center-of-mass corrections need to be applied to the data; these errors are basically the same as those in the NASA systems, since essentially the same equipment and models are used.

8.2 System Noise

The range noise in the SAO lasers is determined in large part by return signal strength.

With LAGEOS, at signal strengths of a few photoelectrons, noise levels were typically 20-50 cm with a 6 nsec wide pulse we anticipate a range noise of 30-40 cm for single photoelectron events. Some additional noise is added through inadequate sampling of single photon events using the WD2000 with a 1 nsec spacing.

9. STATUS AND EVALUATION OF LASER UPGRADING

Through the most recent upgrading program, the performance of the SAO lasers has been improved considerably in terms of accuracy, range noise, data yield, and reliability. With the narrower laser pulse (2.5-3.0 nsec) and a new analog pulse processing system, the systematic range errors have been reduced to 3-5 cm and range noise has been reduced to 5-15 cm on low satellites and 10-18 cm on Lageos. Pulse repetition rate has been increased to 30 ppm and considerable improvement has been made in signal-to-noise ratio by using a 3A interference filter and by reducing the range gate window down to 200-400 nsec. Work continues now to further reduce the laser pulse width and to test a multiple pulse scheme to increase data yield.

The first upgraded system is now in operation in Arequipa, Peru. An upgraded system will be installed in Matera, Italy, in late 1982.

9.1 Hardware Status

The SAO laser systems, prior to the last upgrading are described in detail in Pearlman et al, 1978, and 1981.

In 1979, SAO introduced pulse choppers into its ruby laser systems to reduce laser pulse width. The chopper is a Krytron-activated Pockels cell with entrance and exit dielectric polarizers for necessary transmission and isolation. The optical assembly of the chopper, which consists of a thin-film dielectric polarizer sharpener and analyzer, and a KDP 50 ohm Pockels cell, was designed to fit between the original laser oscillator and

amplifier sections. A Blumlein circuit provides the proper high-voltage pulse to operate the Pockels cell and a PIN diode and avalanche transistor circuit to trigger the system. The Blumlein is essentially a delay-line structure, in which delays and reflections are used to produce a high voltage rectangular pulse of desired width from a voltage step provided by the Krytron. In this upgrading, the length of the ceramic Blumlein was reduced from 15 cm to 5 cm. In addition, the size of the r. f. coupling to the ceramic structure was minimized and all bends and angles were removed to reduce delays and reflections. This reduced the chopped laser pulse width from 6 nsec to about 2.8 nsec (See Figure 3).

Figure 3.

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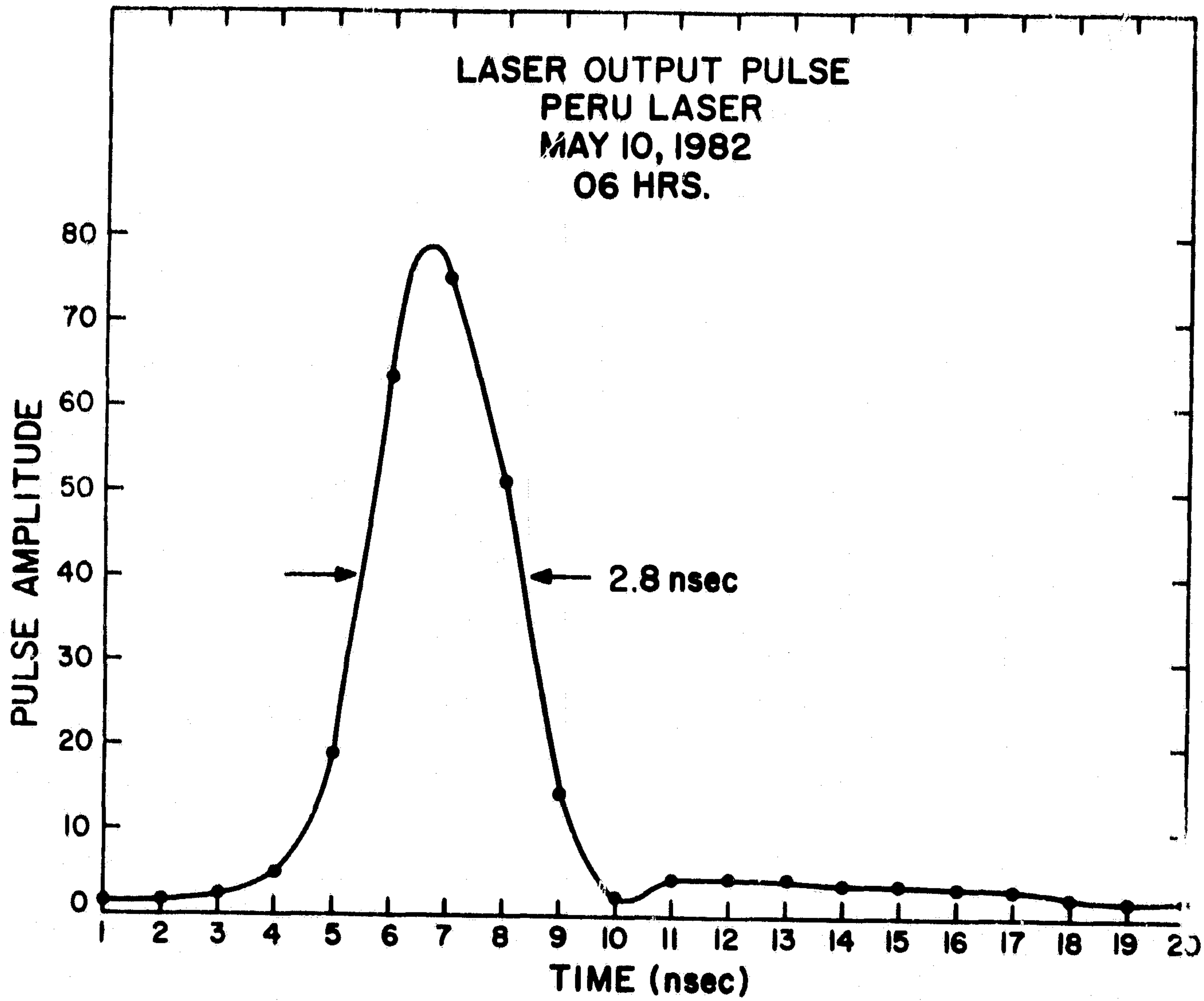

The laser output pulse is sampled by a Hamamatsu, S1188-01, PIN diode through a reflection from an optical window. The diode output is broadened to about 5 nsec with a combinational delay circuit and then applied to a constant fraction discriminator which furnishes the start pulse for the timing system. The broadening is required to place the constant fraction discriminator in a stable region.

The laser power supply control unit has been modified to enable the system to fire at rates up to 30 ppm. The fundamental limitation to repetition rate in the past has been: (1) the tracking regime of the mount which must stop at each point to fire and is thereby limited by rates of speed and acceleration and (2) the speed of on line processing of return waveform digitizer data. We have added the capability of varying the firing rate by satellite and geometry, thus permitting the "slower moving" LAGEOS satellite to be tracked at firing rates up to 30 ppm. The lower "faster moving" satellites are tracked at rates of 10-15 ppm depending upon orbital geometry.

For several years, SAO has been using a waveform digitizer with twenty 1 nsec sampling intervals to record pulse waveshape for determination of pulse centroid. To avoid accuracy limitations (aliasing) due to waveform sampling and to accommodate the faster pulse repetition rate, the waveform digitizer has been replaced by an analog pulse detection system. This detector consists of a matched filter tuned for the laser pulse. The filter is followed by a differentiator and slope-triggered low threshold discriminator, which functions essentially as a cross-over detector. The photo detector has been changed to an Amperex 2233B PMT and EMI Gencom base

which has been modified by: (1) having the ground connection brought out to the PMT base and, (2) replacing the anode wire with 50 ohm cable. The PMT base was then laboratory tuned for minimum distortion of short duration low-level input pulses. The PMT and base configuration were selected as a low cost compromise between (1) fast risetime and good pulse reproduction and, (2) reliability and tolerance for high background noise (anode current). In addition, the front of the PMT has been apertured down to 1.5 cm to reduce jitter. This has reduced the jitter (peak to peak) from about 0.5 nsec to 0.25 nsec as measured with a 100 psec-wide optical pulse generator in the laboratory.

Several modifications were made to improve the signal to background noise ratio. The photoreceiver was modified to add a fast shutter and to replace the 8 Angstrom interference filter with a 3 Angstrom (Day Star) interference filter. The range gate system was upgraded to accept range gate windows down to ± 0.1 microsecond (30 meters). These improvements have increased signal to noise performance by 16-20 db which is permitting the laser to operate on Lageos further into daylight conditions.

The new characteristics of the system are summarized in Figure 4.

Figure 4.

SAO LASER SYSTEM

WAVELENGTH (Å)	6943
ENERGY/PULSE (J)	.3 - .5
PULSE WIDTH (NSEC)	2.5 - 3.0
REP. RATE (PER MIN)	30
DIVERGENCY (MR)	0.6
QUANTUM EFFICIENCY (%)	4
SYSTEM EFFICIENCY (%)	25
RECEIVER DIAMETER (M)	.50
SYSTEMATIC RANGE ERROR (CM)	< 5
RANGE NOISE (CM)	
LAGEOS	10 - 18
LOW ORBITING SATELLITES	5 - 15

The status of the hardware for upgrading the remaining systems is shown in Table 5.

For the Matera system (SAO 1) the laser control unit must be modified for some additional noise suppression. This need was discovered at Mt. Hopkins and will require approximately two man weeks to complete. The analog processor still requires testing at the 2-3 nsec pulse range. This will require approximately one man week of labor. The hardware for Matera will be ready for shipment in early October.

For the SAO 3 retrofit hardware, the Laser Control unit must still be modified for noise suppression and then tested. The analog detector must also be tested out. These activities are scheduled for attention after the Matera laser has been shipped.

Table 5.

Hardware Status

	Laser Power Supply	Laser Control Unit	Range Gate	Photo receiver	Start Circuit	Analog Detector
SAO 1	ready	tested - needs mod.	ready	ready	ready	built needs testing
SAO 3	ready	built needs testing and mod.	ready	ready	ready	built needs testing

9.2 Assessment of Performance

The ranging performance capability of the lasers has been assessed by examination of both systematic errors and range noise. These refer to performance of the ranging machine itself, leaving aside issues such as atmospheric correction, spacecraft center of mass correction, and epoch timing for discussion elsewhere.

9.2.1 Data Yield

In the first 60 days of operation the laser in Arequipa tracked 290 satellite passes, of which 90 were Lageos. Lageos passes averaged 260 points with some going as high as 400-600 points. During a "good" pass, the rate of return was typically 20%-50% depending upon sky conditions and satellite altitude. In many of the passes the satellite was acquired at altitudes as low as 10°, and tracked through zenith back down to 10°.

In the lower orbiting satellites, (Starlette and BE-C), data yield per pass varied from 50-100 points with occasional yields as high as 150 points. Here the rate of return was in the range of 20%-80% with intervals as high as 100%. The low altitude acquisition experience with these satellites was similar to that of Lageos.

9.2.2 Range Accuracy

The systematic errors of the laser system have been divided into three categories: spatial, temporal, and signal-strength variations (See Pearlman 1981A). Spatial variations refer to differences in time of flight depending on the position of the target within the laser beam. Temporal variations relate to system drift between prepass calibration and postpass calibration. Variations in range due to changes in signal strength from pulse to pulse are a function of receiver characteristics.

Spatial Variations

Spatial variations, or the wavefront error, which arise from the multimode operation of the ruby lasers, have been measured at Arequipa using a distant target retroreflector to probe the beam. Figure 5 shows the results for different ruby doping levels. The wavefront measurements on May 11 using the .03% Cr^{++} doped ruby rod show an r.m.s. variation across the wavefront of 1.4 cm and peak-to-peak variations of 4.5 and 5.0 cm. It appears however that a large component of this variation is the temporal stability or measurement reproducibility as evidenced by the averaging of measurements at the beam center. The results on June 4 using the .05% CR^{++} doped ruby are a little worse, showing r.m.s. wavefront distortion of 1.3 cm and 2.0 cm and peak-to-peak variations were of 5.3 cm and 6.9 cm. Once again, a significant component of the wavefront distortion measurement appears to be temporal variation, indicating that these wavefront measurements are probably giving an overestimation of wavefront distortion.

Figure 5.

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WAVEFRONT MEASUREMENT AREQUIPA LASER									
DATE	TIME	SPACING BETWEEN POINTS (ARC MIN)	RUBY ROD POPING	PRF (PER MIN)	AVERAGE* NUMBER OF PHOTOELECTRONS RECEIVED PER PULSE	TEMPORAL STABILITY AT BEAM CENTER		WAVEFRONT DISTORTION	
						RMS (CM)	MAXIMUM EXCURSION (CM)	RMS (CM)	MAXIMUM EXCURSION (CM)
MAY 11	03 HRS	.42	.03%	20	30	1.8	4.1	1.4	5.0
	05 HRS	.42		20	28	1.4	3.3	1.4	4.5
JUNE 4	03 HRS	.42	.05%	20	28	1.5	3.2	2.0	6.9
	06 HRS	.42		30	28	1.5	[illegible]	1.3	5.3

*FIFTY PULSES AT EACH OF TWENTY POSITIONS

The difference between the .03% and .05% doping may not be statistically significant; but the lower doping probably allowed more uniform pumping which may have given a more uniform wave front (mode pattern).

Temporal Variations

The temporal variations or system drift are estimated through electronic and ranging calibrations.

Electronic calibrations using a 3 nsec pulse through a fixed delay line to start and stop the ranging system have been used at Arequipa to estimate the stability of the electronics. An example of the results are shown in Figure 6. The r.m.s. variation of the means is less than 1 cm with peak-to-peak values about 2 cm.

Temporal stability of the full system was measured with the billboard target, ranging over a period commensurate with a Lageos pass. The results are shown in Figure 7. The r.m.s. variation of the set means is .9 cm while the peak-to-peak variation is 3 cm, which is consistent with electronics tests.

Temporal stability is also estimated by the difference between pre-pass and post-pass calibrations to the billboard target. These measurements are taken at about 5 photoelectrons with calibration 50-100 points in each calibration. The results of the first month of ranging is shown in Figure 8. After an initial "experience period" the pre-post differences settled down to an r.m.s. variation of .16 nsec (2.4 cm). In

mid-May we experienced two problems, one with the laser and one with the counter. The laser problem resulted from light leakage through the pulse chopper giving early returns which degraded system performance. The problem with the counter was an occasional degradation of stability at the level of a few tenths of a nanosecond. The laser problem appears to have been cleared up through adjustment and change of components. The counter situation has been improved but the stability is still a problem as is evidenced by the 50% degradation in pre-post calibration data in late May and early June. A replacement counter is on route to the station.

Figure 6.

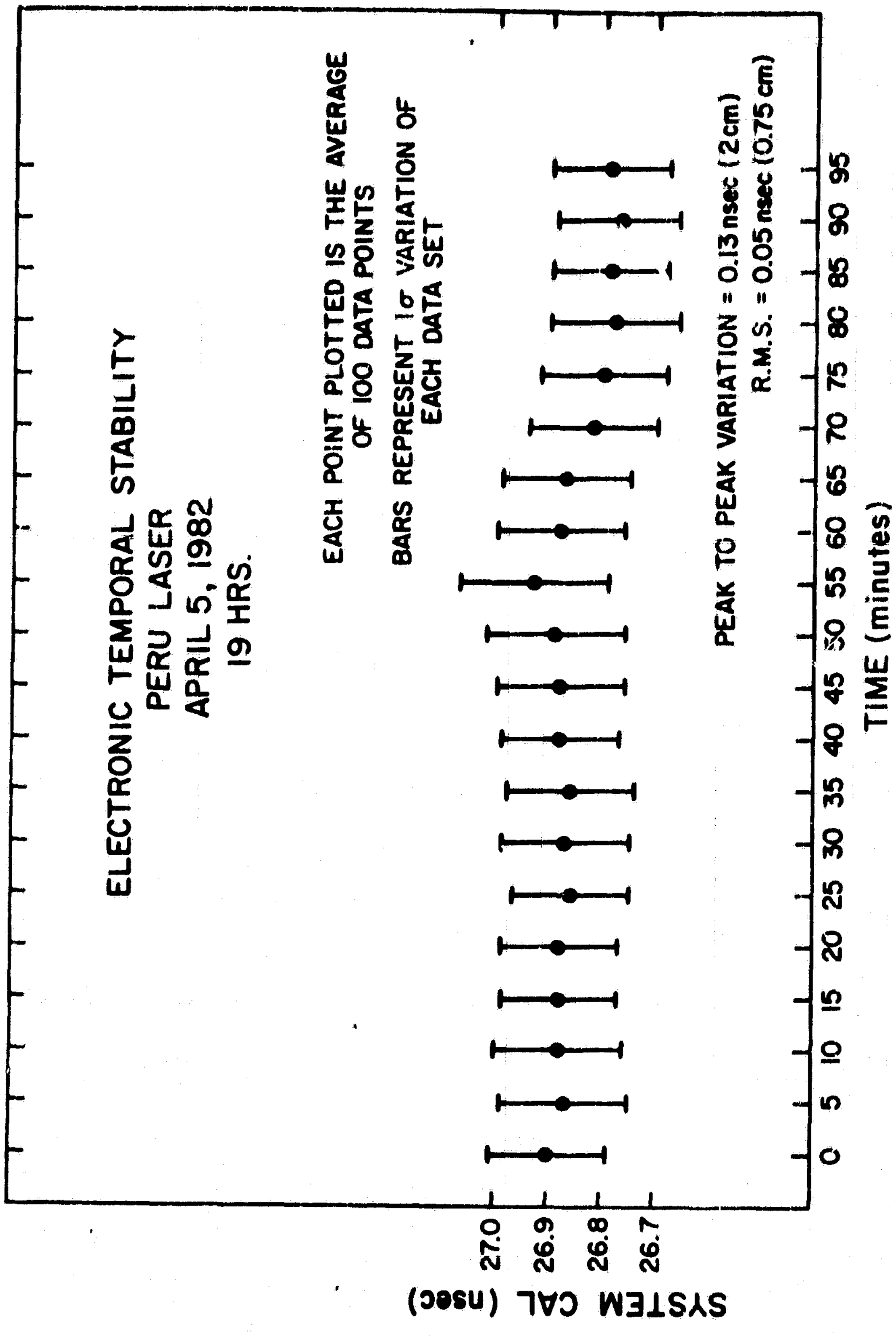
ELECTRONIC TEMPORAL STABILITY
PERU LASER
APRIL 5, 1982
19 HRS.
EACH POINT PLOTTED IS THE AVERAGE OF 100 DATA POINTS
BARS REPRESENT 1σ VARIATION OF EACH DATA SET
PEAK TO PEAK VARIATION = 0.13 nsec (2cm)
R.M.S. = 0.05 nsec (0.75 cm)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
TIME (minutes)
27.0
26.9
26.8
26.7
SYSTEM CAL (nsec)

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Figure 7.

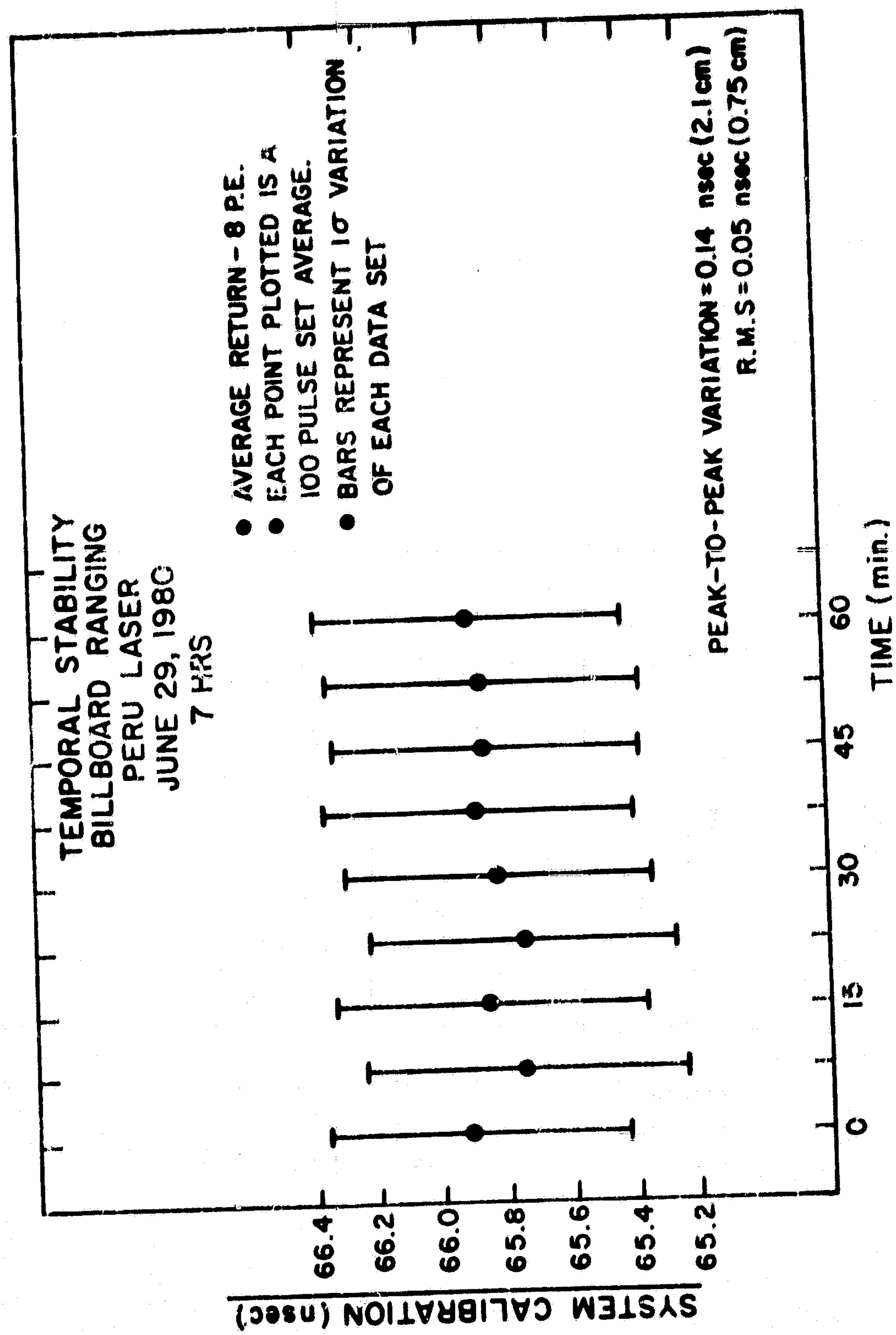
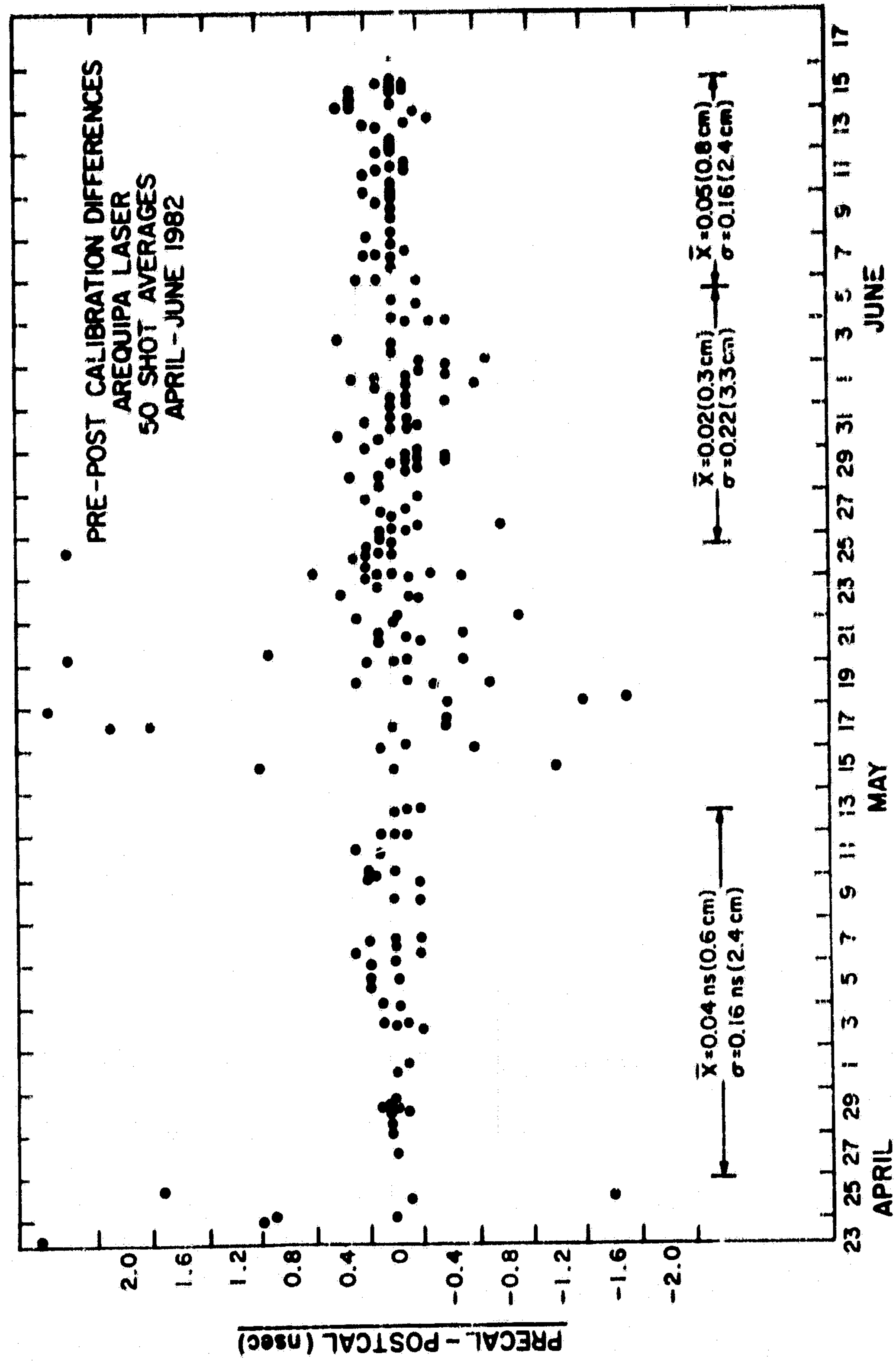


Figure 8.


PRE-POST CALIBRATION DIFFERENCES
AREQUIPA LASER
50 SHOT AVERAGES
APRIL-JUNE 1982
X̄ = 0.04 ns (0.6 cm)
σ = 0.16 ns (2.4 cm)
X̄ = 0.02 (0.3 cm)
σ = 0.22 (3.3 cm)
X̄ = 0.05 (0.8 cm)
σ = 0.16 (2.4 cm)
2.0
1.6
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
-1.6
-2.0
PRECAL - POSTCAL (nsec)
APRIL
MAY
JUNE

Signal Strength

The SAO lasers operate at the single photoelectron level on Lageos and in the range of 1-50 photoelectrons on low orbiting satellites. Variations in apparent range with signal strength have been examined with extended target calibrations over the dynamic range of the laser instrument (See Figure 9 and 10). The mean calibration over the operating range of 1-50 photoelectrons is typically flat to ± .15 nsec (2.2 cm) with maximum peak-to-peak excursion of .3 nsec (4.5 cm). We believe that the lowering trend at lower signal strengths is due to non-optimization of the matched filter. The matched filter was optimized for nearly symmetrical laser output pulse, whereas the single photoelectron pulses tend to be somewhat asymmetric.

A summary of the range error components are tabulated in Figure 11. Assuming that these errors are independent, the root-sum square (rss) error due to the r.m.s. systematic sources is about 4 cm. We use this value to characterize the systematic errors that can be expected for data averaged over a pass.

Figure 9.

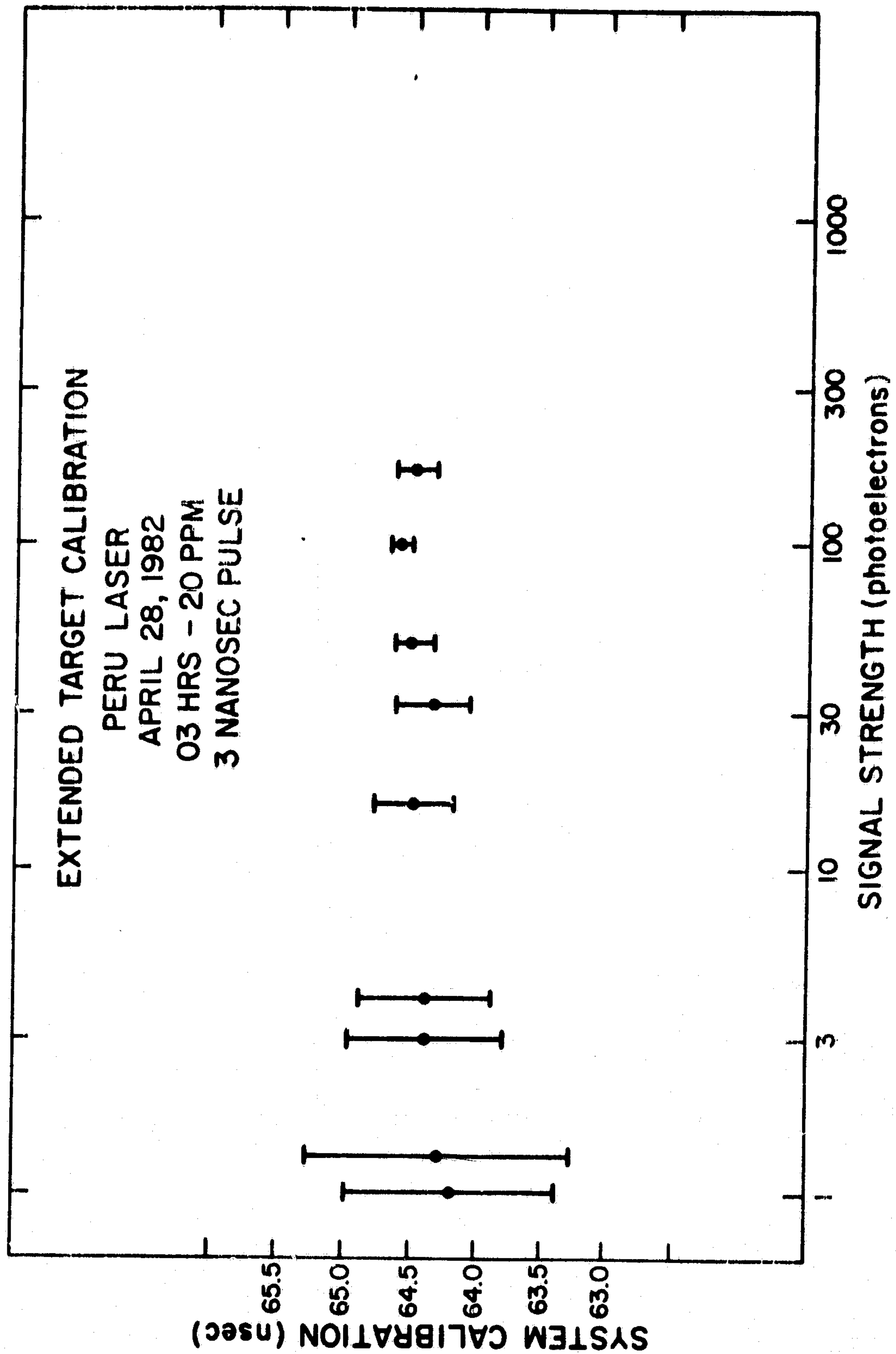

EXTENDED TARGET CALIBRATION
PERU LASER
APRIL 28, 1982
03 HRS - 20 PPM
3 NANOSEC PULSE
SIGNAL STRENGTH (photoelectrons)
1
3
10
30
100
300
1000
SYSTEM CALIBRATION (nsec)
65.5
65.0
64.5
64.0
63.5
63.0

Figure 10.

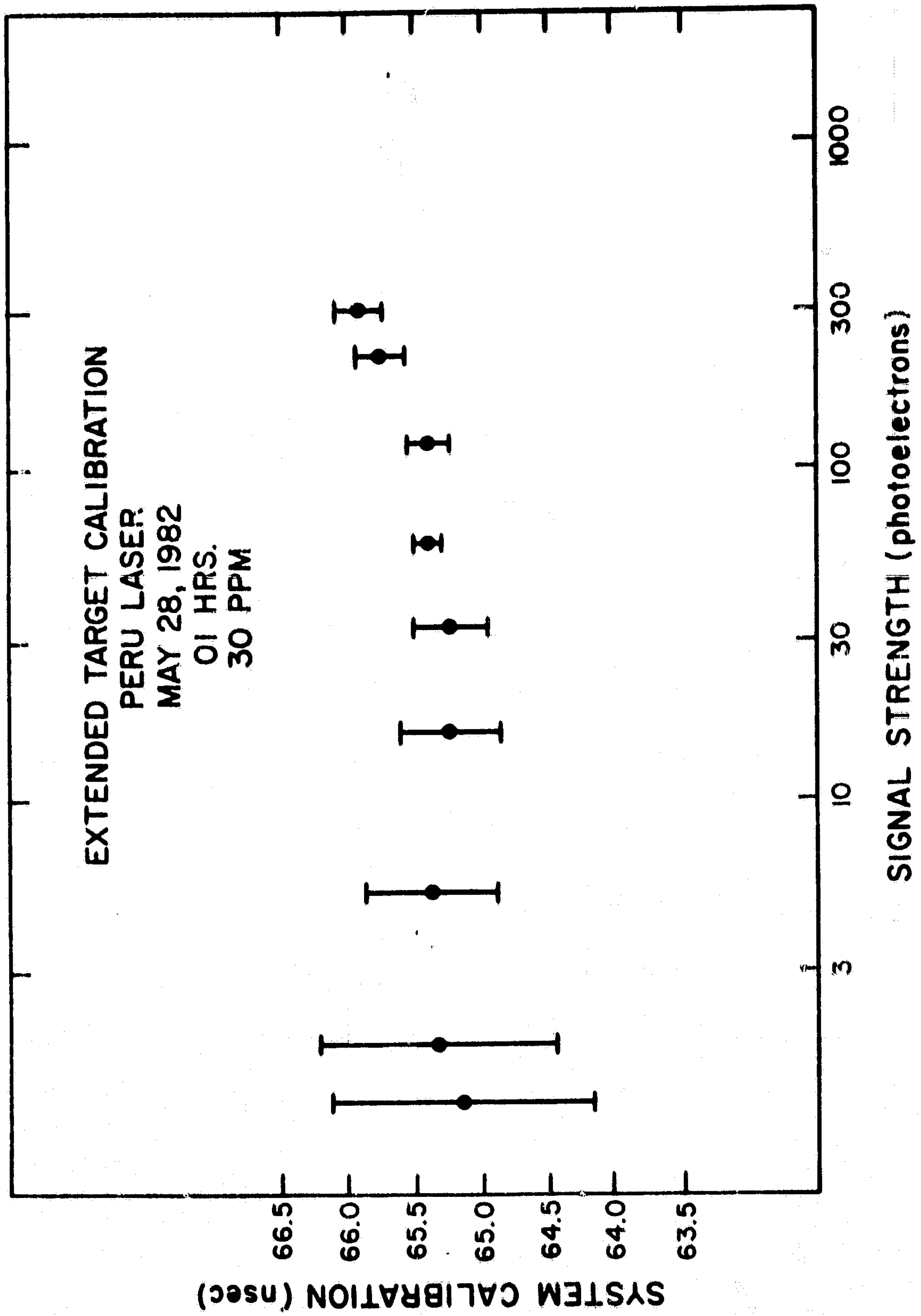

EXTENDED TARGET CALIBRATION
PERU LASER
MAY 28, 1982
01 HRS.
30 PPM
SIGNAL STRENGTH (photoelectrons)
3
10
30
100
300
1000
SYSTEM CALIBRATION (nsec)
66.5
66.0
65.5
65.0
64.5
64.0
63.5

Figure 11.

SAO LASER NETWORK

SYSTEMATIC ERROR SUMMARY

SOURCE	EST. ERROR (RMS)	EST. ERROR (PEAK)
WAVEFRONT (SPATIAL)	2.0 CM	5.0 CM
SYSTEM DRIFT (TEMPORAL)	2.4 CM	6.0 CM
CALIBRATION (SIGNAL STRENGTH)	2.2 CM	4.5 CM
R.S.S.	3.8 CM	9.0 CM

9.2.3 System Noise

The noise performance of the system has been measured by examining range noise (1σ) verses signal strength in calibration runs on the billboard target. This has the advantage of highlighting system jitter by averaging out effects of wavefront distortion. The results of several calibration sequences are shown in Figure 12, along with the theoretical results for a 3 nsec gaussian pulse for reference. At low and intermediate signal strengths, the range noise follows closely the anticipated $n^{-½}$ dependence and is consistent with a pulse of about 3 nsec width. At high signal strengths, the system noise levels off at about .2-.3 nsec (3-4.5 cm) which is probably dominated by the jitter in the P.M.T.

The distribution of range residuals (1σ) on a per pass basis for Lageos, Starlette, and BE-C during the first 60 days of operation at Arequipa are shown in Figures 13, 14 and 15. Range noise on Lageos varies typically from 12-18 cm as would be anticipated for 1-2 photoelectron events with a 3.0 nsec wide pulse. There is probably some corruption due to the jitter in the electronics and the PMT. All of the events with 1σ values above 30 cm occurred during the period May 15-25 when we were having equipment problems.

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Figure 12

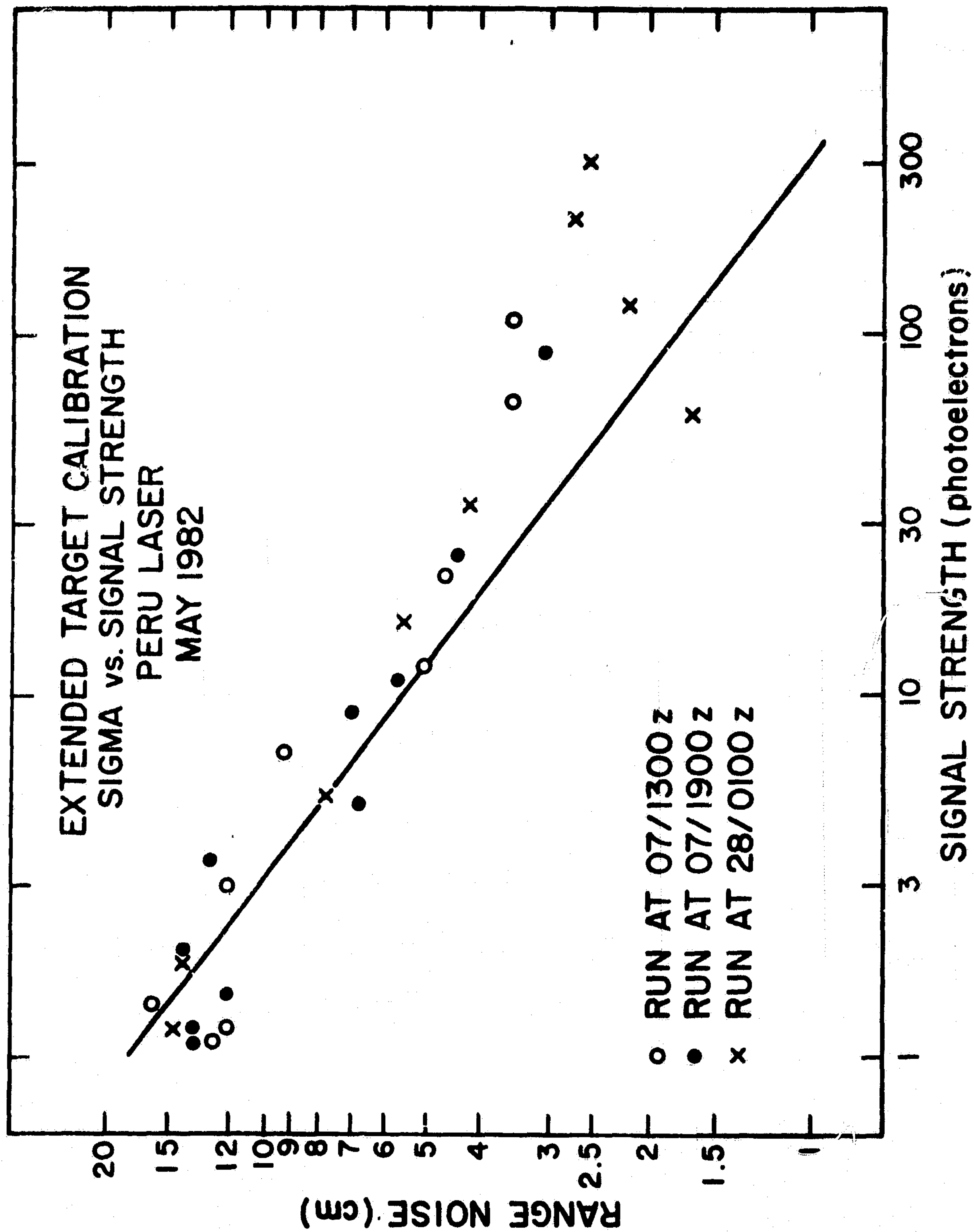

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Figure 13

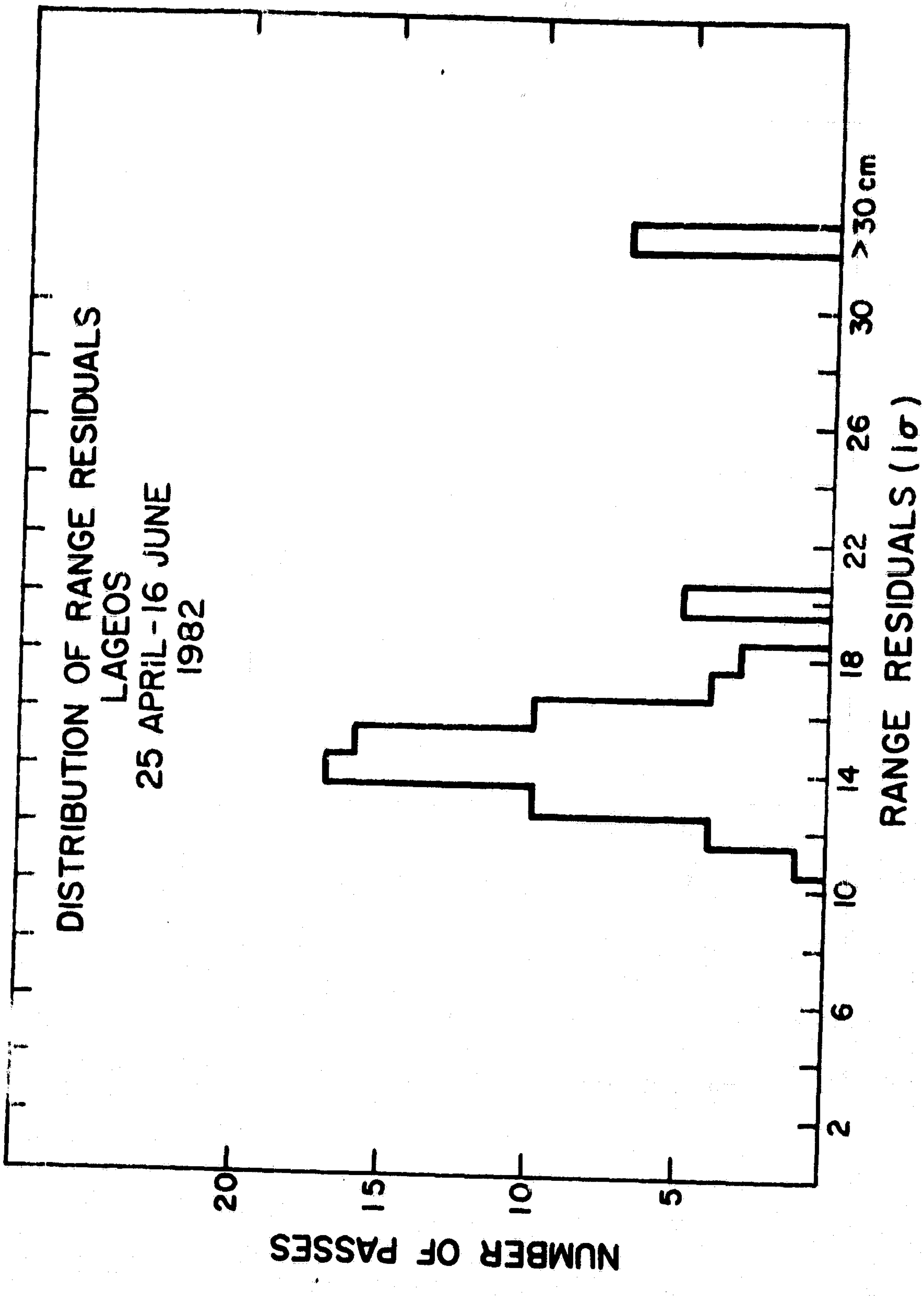


Figure 14

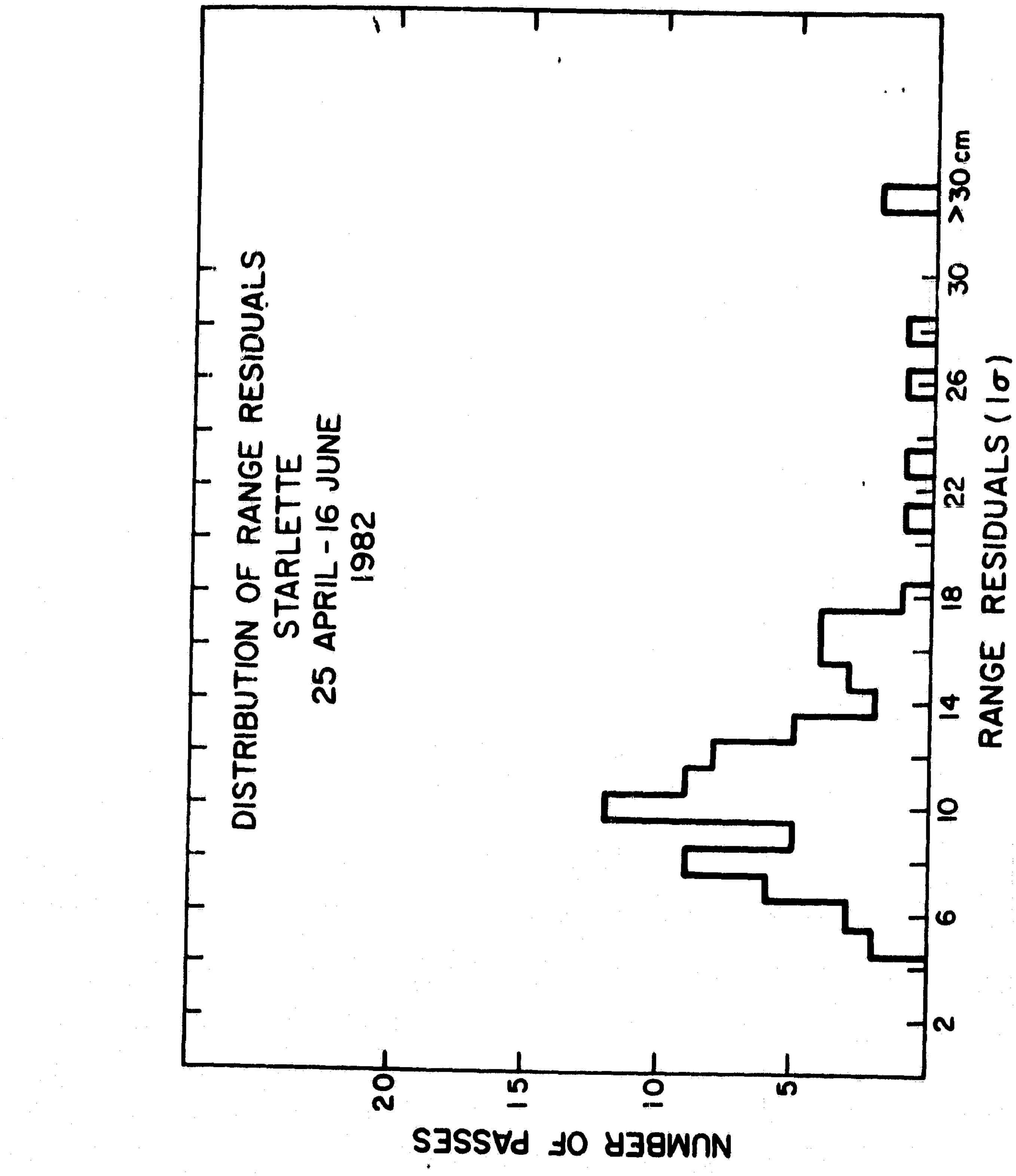
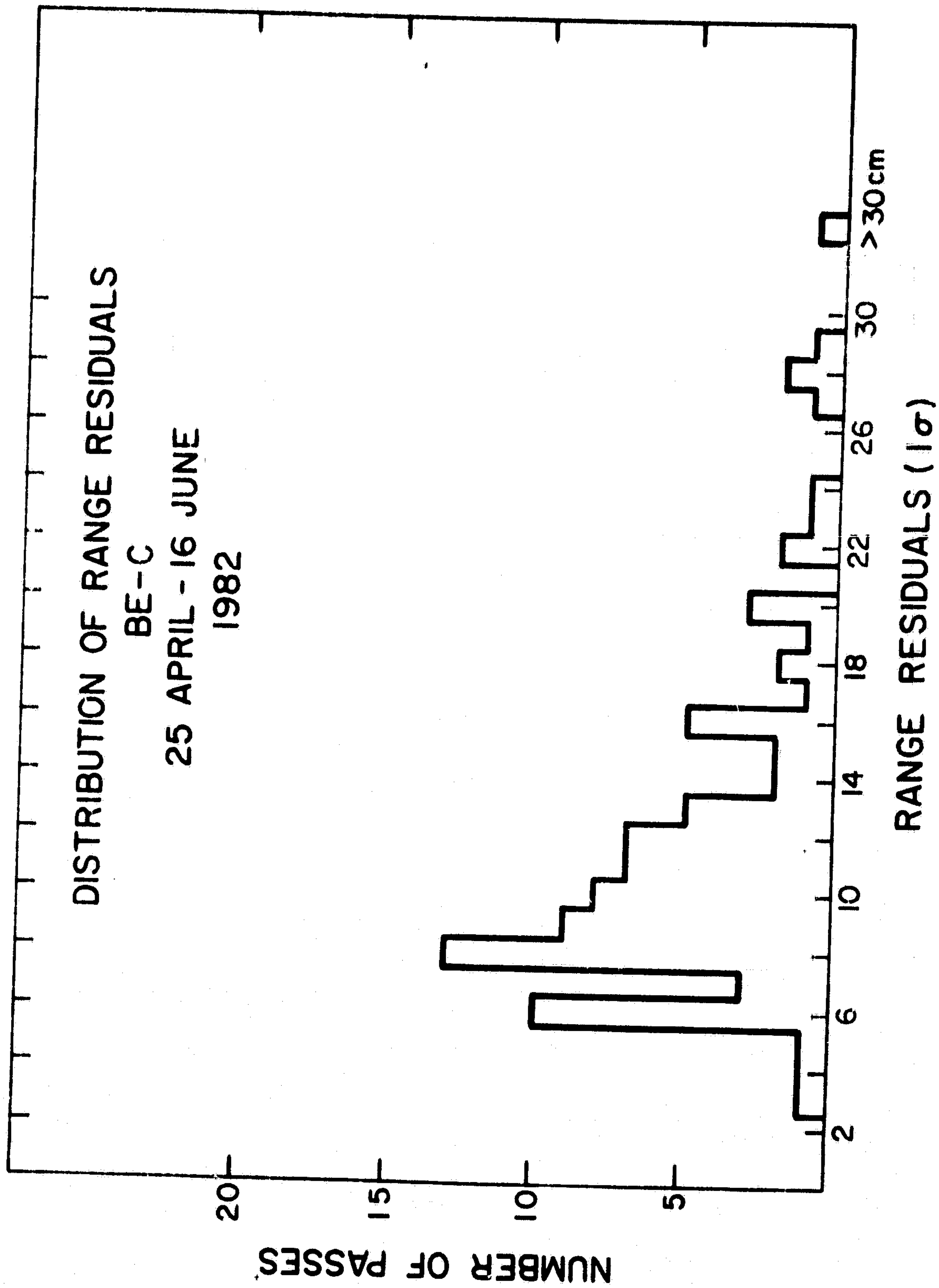

DISTRIBUTION OF RANGE RESIDUALS
STARLETTE
25 APRIL-16 JUNE
1982
NUMBER OF PASSES
20
15
10
5
RANGE RESIDUALS (1σ)
2
6
10
14
18
22
26
30
>30 cm

Figure 15


DISTRIBUTION OF RANGE RESIDUALS
BE-C
25 APRIL - 16 JUNE
1982
NUMBER OF PASSES
5
10
15
20
RANGE RESIDUALS (1σ)
2
6
10
14
18
22
26
30
>30cm

On the lower satellites, returns signal strength are typically 5-30 photoelectrons. Short arc fits to quick-look data give r.m.s. values of 5-18 cm. At the higher signal strengths, the range jitter in the PMT and the electronics becomes significant and tends to degrade the $n^{-1/2}$ noise dependence.

10. RELOCATION OF SAO 1 TO MATERA, ITALY

In response to NASA direction, the Natal laser (SAO 1) operation was closed out on 30 September 1981. The laser equipment was packed and shipped to SAO. The local staff was released and the U.S. Observers were returned to the U.S.

NASA, SAO and representatives of the Italian National Space Council (a part of the CNR) have agreed on the relocation of SAO 1 to Italy. Under an agreement reached, the laser will be relocated to a mutually-agreed upon site at CNR expense and they would take responsibility for operations. SAO would provide headquarters support, configuration control, and network integration and coordination. Several meetings were held at SAO with representatives of CNR and Telespazio to familiarize the Italians with technical aspects of the program.

In March, representatives from SAO met with CNR and other Officials in Italy to assess a candidate site in Matera and to work out some of the preliminary issues. A trip report with an evaluation of the site is included in Appendix 1. The CNR has also furnished the requested information on cloud cover (see Appendices 2 and 3) and a building design. Based on the trip and the information submitted, the site at Matera has been approved as has the building design.

Weather data for the years 1979 and 1980 for Ginosa Marina, which is within 10 miles of Matera, is shown in Figure 16. It appears that there are three very good months (July, August and September) and three fair months (May, June and December) for optical observations. The other six

months are marginal. Unfortunately, the clear season comes during the summer when night time hours are at a minimum. On the positive side, the weather pattern is common to most of Europe and the Mediterranean area so that all stations should be experiencing good weather at the same time, thereby maximizing our opportunity for baseline measurements.

We have reviewed the building design. Several minor modifications were required, but these should be easily accommodated. A schedule based on the current situation is shown in Figure 17. Building construction will not be underway until mid-August at the earliest. This projects equipment setup in January 1983 and operations in the April 1983 timeframe. Based on this schedule, we will not ship the equipment until October 1982. In an attempt to expedite things at Matera, we will do as much of the upgrading modifications and testing in Cambridge before the equipment is shipped.

SAO engineers will go to the site in January for system setup (including upgrading) and training. We anticipate that the system will be in operation in April 1983.

A draft agreement between SAO and CNR covering our basis of understanding at the working level is included in Appendix 4.

Figure 16

Weather Chart

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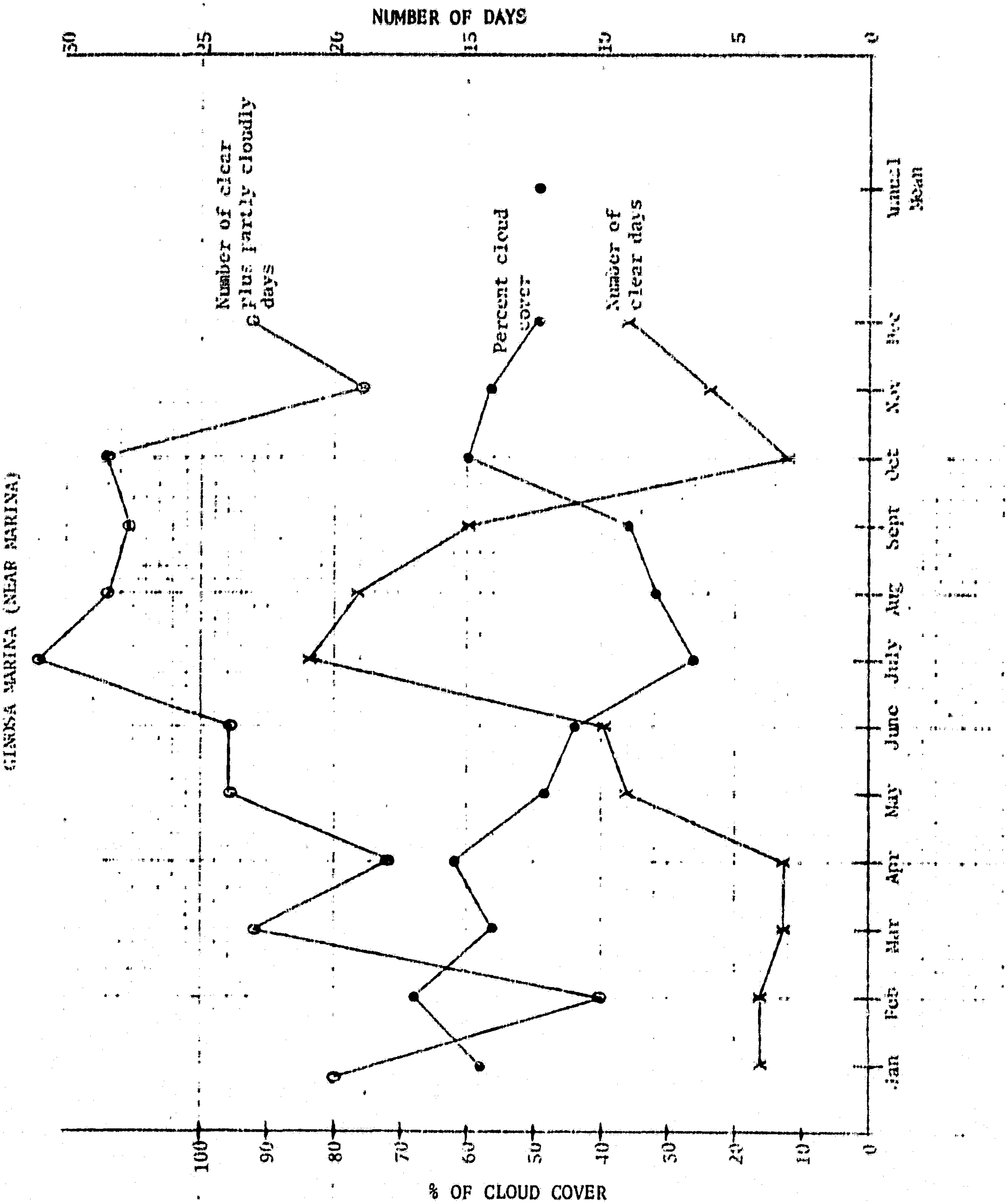

SCHEDULE

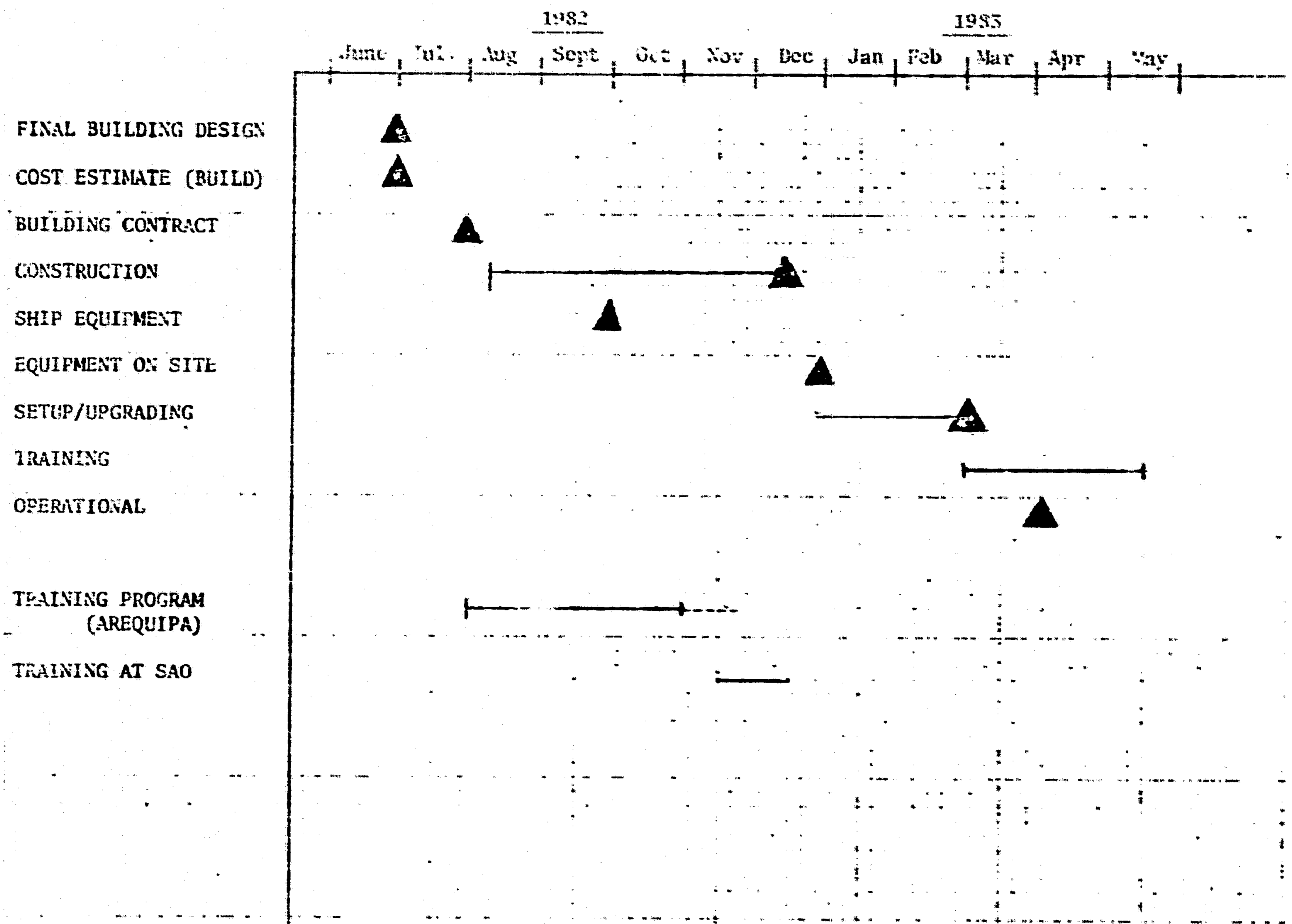

Figure 17

11. STATUS OF SAO 3 AND 4

The laser system from Orroral Valley (SAO 4) is being returned to SAO. Several key items from the system such as the minicomputer and the time interval counter have or will be shipped to the operating field sites as backup units. The remainder of the equipment will be placed in storage.

The system electronics and minicomputer from the Mt. Hopkins laser have been returned to Cambridge and are being set up as a laboratory and diagnostic test facility for the other lasers. The rest of the equipment including the laser, the photoreceiver, and the mount will remain in storage at Mt. Hopkins.

Packages for upgrading both of these systems have been built and will be tested in early FY83. Both systems are available for relocation.

12. PERSONNEL

12.1. Travel

After the Natal, Brazil station close-out was completed in December, Dana Seaman and Donald Patterson, both former Observers from that station, travelled to Mt. Hopkins, Arizona, in January for temporary assignments to assist Noel Lanham in upgrading the laser system there and in closing the station. Mr. Seaman then returned to headquarters in February for a temporary assignment in software development prior to his terminating from SAO. In May, Mr. Patterson returned to Headquarters to work with the Engineering group.

Mr. James Maddox, Electronic Engineer, travelled to Mt. Hopkins for a few weeks in February to install and test the new Blumlein, as part of the upgrading program.

Mr. Jakob Wohn travelled to Arequipa in March and remained thru June working on the upgrading of the laser system. Mr. J. Paul Ouellette, Electronic Engineer, joined Jake in April to help implement the electronic changes for the upgrading.

On the 12th of January, Mr. James H. Latimer travelled to Washington, DC to attend the meeting of the US MERIT Committee during which an outline of the scientific objectives of the MERIT Campaign was presented.

At various times during the reporting period, Dr. Michael R. Pearlman, Richard Taylor, John Thorp and James Latimer each travelled to Goddard Space Flight Center to attend the Crustal Dynamics meetings in support of the Mission Contract.

Dr. Michael Pearlman and John Thorp travelled to Rome, Italy during the last week of March to meet with Dr. Guerriero of the Consiglio Nazionale delle Ricerche (CNR) and officials from the University of Bari, Telespazio, the City of Matera and the region of Basilicata to hold discussions and to reach an agreement concerning the proposed Italian laser site at Matera. Approval was granted for a site there and agreements between CNR and NASA have been ongoing. This trip was funded by the CNR.

Upon leaving Italy, Dr. Michael R. Pearlman travelled to Helwan, Egypt, for programmatic and technical discussions with scientific and administrative personnel concerning the discontinuance of excess currency funding to help support the cooperating station there. This trip was funded by excess currency grant FC70225900.

Dr. Michael R. Pearlman, Mr. James Latimer and Mr. James Maddox travelled to Bendix Engineering, Maryland, to attend the Fourth Satellite Laser Ranging Conference. Dr. Michael Pearlman was a guest speaker there and gave a presentation entitled "SAO Operations and International Interface".

In June, Dr. Michael R. Pearlman and Mr. David Arnold travelled to Goddard Space Flight Center for a day to attend the Joint NASA-PSN Lageos II Working Group meeting.

12.2 Visitors

Dr. Caparelli, vistor to the Massachusetts Institute of Technology from Telespazio, Inc. of Italy, visited with Dr. Michael R. Pearlman on the 19th of May to discuss the proposed laser site in Italy and to plan future administrative meetings concerning the setup of operations there.

Later in the month, Drs. M. Caputo and S. Zerbini, both from the University of Bologna, Italy, along with Dr. M. Roufosse of SAO, met with Dr. Pearlman to hold scientific and administrative meetings concerning the research to be conducted with the cooperating agencies at the proposed Italian site.

Mr. Franco Palutan of Telespazio, an Italian space contract firm, awarded the contract for construction of the laser system in Italy, met with Dr. Pearlman and other administrative staff on 7 June to discuss the status of the laser relocation to Matera, Italy. The building design for the station and weather data were reviewed as were details of the Network operations and data acquisition.

Dr. Barbara Kolaczek, a visiting scientist from the Polish Academy of Sciences, Space Research Center, of Warsaw, Poland, arrived at SAO in June to pursue a cooperative program in Polar Motion Analysis.

12.3 Personnel

Mr. Preston R. Clark, Network Logistics Officer, retired from SAO on 28 May 1982. Mr. Clark, who first joined the Satellite Tracking Program in 1963, then left for a brief time to return again in May 1965, served as Administrative Services, Supply, and Logistics Officer for the Network during a period of almost 20 years. Mr. Clark brought to the Smithsonian his considerable experience as a Naval Supply Officer, being a retired U.S. Navy Commander, and was a fundamental part of field operations for the many years of his service to the Smithsonian.

Due to the close-out of the Mt. Hopkins station, Mr. Russell Warner was terminated from his position of Station Manager on May 28th. He returned to Headquarters for a short period for technical and administrative debriefing prior to his termination.

Also due to budgetary constraints, Mrs. Constance Wood was terminated from her position as a Data Specialist at Headquarters on the 28th of May after 24 years of service to the Network.

References

Latimer, J. H., D. M. Hills, S. D. Vrtilek, A. Chaiken, D. A. Arnold and M. R. Pearlman, An Evaluation and Upgrading of the SAO Prediction Techniques. Presented at the Fourth International Workshop on Laser Ranging Instrumentation in Austin, Texas, October 1981.

Pearlman, M. R., N. W. Lanham, J. Wohn, J. M. Thorp, E. Imbier, F. D. Young, J. H. Latimer and I. G. Campbell, 1978. A report on the Smithsonian Astrophysical Observatory Laser Ranging Systems, presented at the Third International Workshop on Laser Ranging Instrumentation, Lagonissi, Greece, in May.

Pearlman, M. R., N. W. Lanham, J. Wohn, and J. Thorp, 1981. A report on Current Status and Upgrading of the SAO Laser Ranging Systems, presented at the Fourth International Workshop on Laser Ranging Instrumentation, Austin, Texas, in October.

Appendix 1
SMITHSONIAN ASTROPHYSICAL OBSERVATORY

M E M O R A N D U M

To: For the Record

From: Dr. Michael R. Pearlman

Subject: Visit to the Proposed Italian Laser Site at Matera

Date: April 13, 1982 C-40

John Thorp and I visited the proposed laser site at Matera. In addition, we met with officials of: the Consiglio Nazionale delle Ricerche (CNR), the University of Bari, Telespazio, the City of Matera, and the Region of Basilicata. Although this project is being run by the CNR with contractor support by Telespazio, the University will be heavily involved in the project planning and scientific analysis. In addition, town and regional authorities must furnish local (site) support and in essence hold a veto over the project.

At a meeting with representatives from all of the above groups, there was a bit of horse trading, and then the President of the Region and Dr. Guerriero of CNR came to agreement and approval was given for the site. With the CNR budget already approved, the Italians are now ready to proceed.

The Site

1. The site is actually about 10 miles east of the city of Matera. It is readily accessible from the standpoint of logistics, services and personnel access. Although there are as yet no utilities at the site, power and water are in the area. The site is already serviced by a dirt road.

2. For communications to the U. S., the Italians are considering telex to a point of entry into the ESA Communications Network and then to NASCOM through either Paris or Madrid. They are also considering GE Mark III and/or Autodin.

3. The site is on a plateau area which is about 1500 feet above sea level. There is no obstruction of the horizon above a few degrees and there is sufficient access in all directions for ground targets at ranges from 1-20 km.

4. The area was originally wooded, but through improper harvesting over many years, most of the vegetation is gone and most of the top-soil has

been eroded away.

5. Bedrock is present at the surface or within a meter of the surface almost everywhere in the region. We examined the immediate area in some detail. There a few local depressions of 2-5 meters which may have been caused at some time by local subsidence. These areas have vegetation in them now. The station and the targets would be located far from these regions.

   To get some idea of the rock cross-section in the area we visited a local quarry. Beneath the surface, the rock is solid; the quarry goes down 100-200 feet, but local estimates indicate that the rock depth is a least 1000 feet thick.

6. The geological structure in all of Italy is very complicated. The southeast part of the country is on the Adriatic Plate. Matera is about 30-40 miles east of the Alpine Mountain building region and as such is on this plate. There have been recent large earthquakes in Potenza, which is only 65 miles to the west, but there has been very little seismic activity reported in the region from Matera eastward. Matera has been continuously occupied since prehistoric time with stone structures dating back several thousand years. Some of these structures are located on the sides of hills and appear very fragile. Yet there is no evidence of any damage to ground motion.

   Just south of Matera (west of the site) there is a deep gorge with a river flowing at the bottom. Our guess is that the gorge was formed by a doming, cracking and rerouting of the river. Again the integrity of the caves and stone structures along the sides of gorge indicate that there has been no appreciable seismic activity in the area for several thousand years.

7. Although seismicity appears to be low, the geological maps do show faults in and around the Matera area. It will probably be necessary to establish a ground survey program to periodically survey the site with a reference network to the more stable eastern region to make sure that any local motions at the site are carefully monitored. The Italians are aware of this and are prepared to carry this out as part of tracking program.

8. The weather in southern Italy is supposed to be excellent. Most of the time the prevailing winds are from the north bringing clear skies and very low humidity. The Matera region is basically a desert. When the winds are from the south (from North Africa), the skies will be cloudy, with fog, haze and rain due to moisture collected over the Mediterranean Sea. Occasionally they get dust storms and "chinooks" (warm, dry winds).

   Unfortunately, when we were at the site, the wind was blowing from the South. We were assured that this was the "visitor effect". They have agreed to provide a cloud cover data for the past several years for review before we proceed on the building. They have the data in

hand, but it will require some consolidation which they are doing now.

The site has fairly constant winds of 5-10 mph. Because of the flat terrain, the flow is laminar and can be accommodated if necessary by building design.

Site Tradeoffs

The CNR and the University of Bari understand that interpretation of motion of the site at Matera may be difficult. The choice of site however is probably the best compromise that we will find at the moment. In addition, the political pressures are very strong. Dr. Guerriero understands that it may be advantageous to move the laser sometime in the future.

Action items and other considerations

1. CNR/Telespazio will furnish cloud cover and other meteorological information by the end of April.

2. Telespazio will complete the building design by the end of April for our review.

3. Telespazio is considering sending a man to Arequipa and then Cambridge for O. J. T.

4. The laser equipment will be ready for shipment by 30 June.

5. CNR will respond formally to NASA on the agreement.

6. SAO and the CNR will conclude an agreement to cover setup, operation, and reimbursement for SAO costs. A draft of this agreement should be available for discussion in late April.

7. Once the agreements have been concluded and the building plan has been approved by SAO, construction will begin.

Appendix 2.

Meteorological Conditions of the Site Selected for the Installation of the SAO Laser Station

The following note contains an extract from information published in the Annual of Meteorological Statistics, Vol. 19, 1979 edition, and Vol. 20, 1980 edition, published by the Central Statistics Institute.

The site selected for the installation of the SAO laser station is about 9 km to the east of Matera, on the plateau of Murge; the coordinates are 40 degrees 39 minutes N, 16 degrees 42 minutes E, and the height is about 500 m slm.

The meteorological observatories nearest to the site are Gioia del Colle (40 degrees 48 minutes N, 16 degrees 55 minutes E, 365m slm) and Ginosa Marina (40 degrees 26 minutes N, 16 degrees 53 minutes E, 12 m slm); for precipitation only, also considered is the meteorological station of Altamura (40 degrees 49 minutes N, 16 degrees 33 minutes E, 461 m slm).

In Table 1 are statistics indicating the precipitation, the atmospheric pressure, the humidity, and the state of the sky for the years 1978 and 1979; precipitation is represented in graphic form in Figure 1 (monthly averages).

In Table 2 are given the frequency and the average velocity of the ground winds, as a function of the direction; in Figure 2 the same data are presented in graphic form.

It is observed that:

1. The annual precipitation is significantly less than the national average.

2. The level of precipitation observed at Ginosa Marina (on the Ionic Coast) is less than that observed at Gioia del Colle (in the interior, about 35 km from the coast). At the selected site, the situation could be intermediate, as shown for Altamura.

3. The monthly profile of precipitation shows a minimun in the summer months and a maximum in the winter months.

4. As for the ground winds, the clearly predominant directions are N-NW and S-SE (Figure 2); the velocities average about 10 knots (1 knot = 1852 meters/hours); the maximum monthly velocities average about 35-50 knots. The wind data are taken three times a day for a total of 1095 observations per year.

5. As for the state of the sky, the data are taken from 4 to 8 times per day, and are expressed in tenths of sky coverage; the day is classified as clear if the average cloud coverage is less than three tenths, cloudy if it is greater than eight tenths, and mixed in the intermediate cases. The observations of the state of the sky are "by eye," and perhaps these data should be interpreted cautiously.

TABLE AND FIGURE CAPTIONS

Table 1
Headings across the top of the page (L to R)

Station, Coordinates, Year, Precipitation (Quantity in mm; frequency in gg),
pressure (in mbar), relative humidity, state of the sky during the day--clear, mixed, cloudy.

Headings along the side
Station Names

National Average

Table 2

Headings across the top, L to R
Ground Winds
Station, Direction, Frequency, Velocity (in knots) for 1978; same for 1979

Headings along the side
Station Names.

Sight translation PWarner 5-21-82

STAZIONE	COORD.	ANNO	PRECIPITAZIONI QUANT. mm	PRECIPITAZIONI FREQ. gg	PRESS. mbar	UMIDITA' RELATIVA %	STATO DEL CIELO GIORNI SERENI	STATO DEL CIELO GIORNI MISTI	STATO DEL CIELO GIORNI COPERT
Gioia del Colle	40° 48' N	1978	720.0	86	1015	76	108	161	96
	16° 55' E	1979	747.0	84	1015	74	106	144	115
	365 m slm								
Ginosa Marina	40° 26' N	1978	475.2	59	1014	75	130	142	93
	16° 53' E	1979	603.6	62	1013	75	107	158	100
	12 m slm								
Altamura	40° 49' N	1978	519.6	80					
	16° 33' E	1979	518.6	82					
	461 m slm								
Media Nazionale		1978	997.0	89	-	-	103	148	114
		1979	962.2	95	-	-	91	154	120

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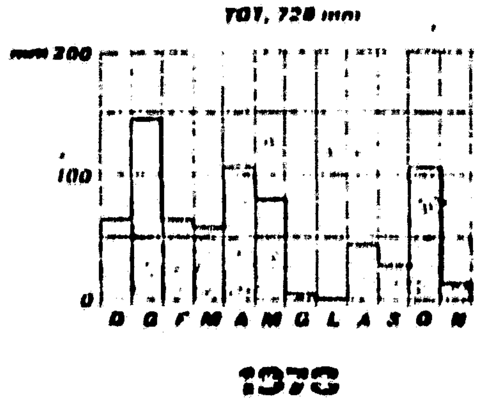
Tab. 1

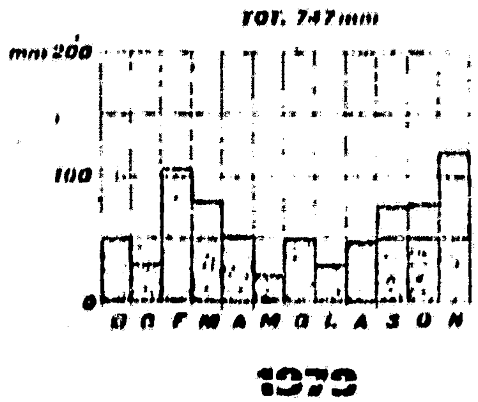
VENTO AL SUOLO

STAZIONE	DIREZIONE	1978 FREQUENZA	1978 VELOCITA' nodi	1979 FREQUENZA	1979 VELOCITA' nodi
Gioia del Colle	N	268	10	202	9
	NE	25	5	22	8
	E	7	10	4	4
	SE	146	14	121	15
	S	167	9	194	11
	SW	29	7	40	11
	W	32	11	47	11
	NW	142	10	139	11
	Variabile	2	-	1	-
	Calma	277	-	325	-
Ginosa Marina	N	175	3	126	9
	NE	30	6	30	10
	E	67	9	60	11
	SE	163	11	165	13
	S	81	9	97	11
	SW	81	7	61	12
	W	78	7	102	8
	NW	335	8	244	9
	Variabile	-	-	-	-
	Calma	85	-	210	-

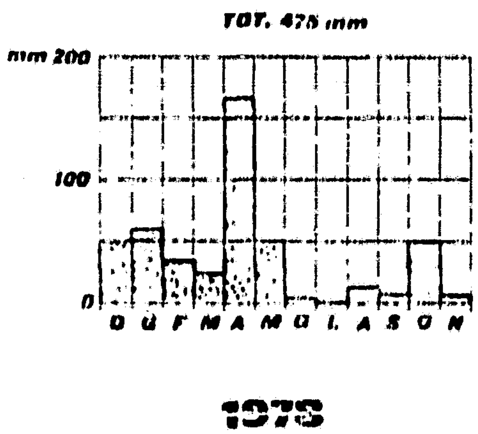
tab. 2

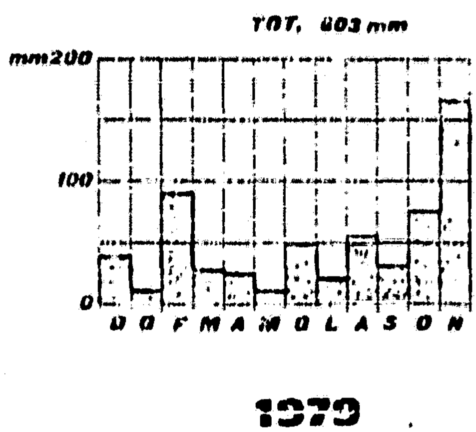
GIOIA DEL COLLE



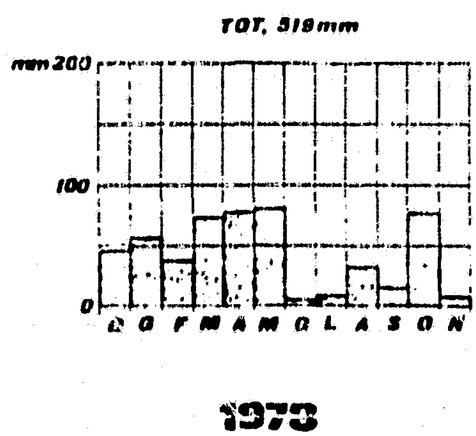


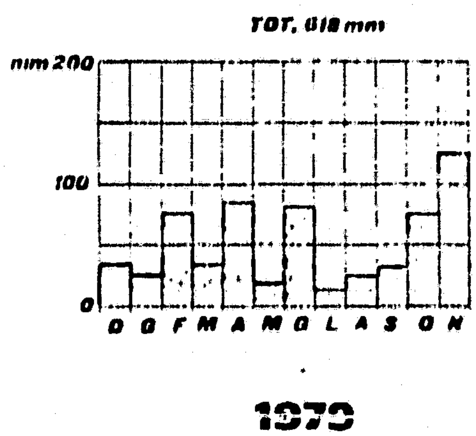
GINOSA MARINA



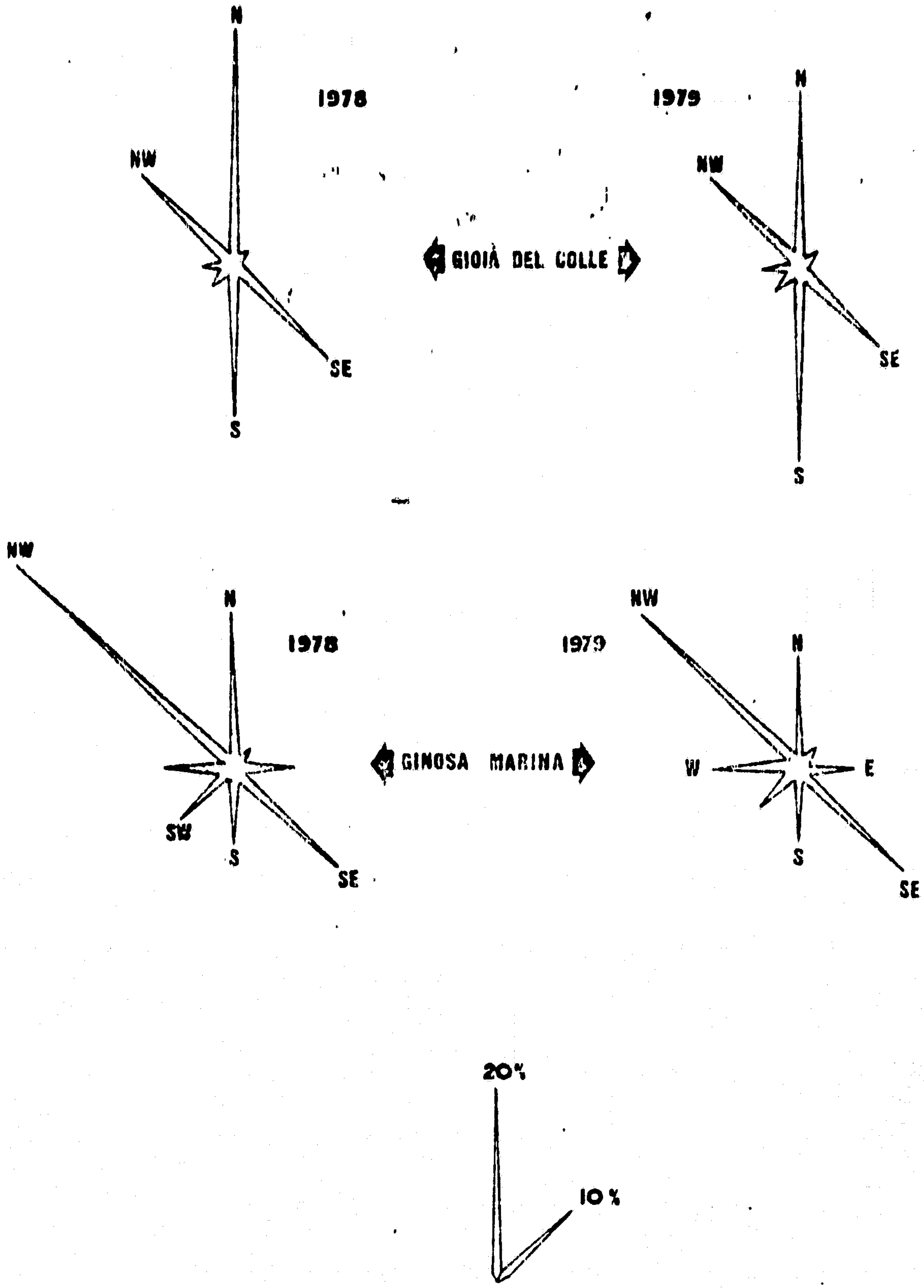


ALTAMURA





FREQUENZA VENTO (SU 1095 OSSERVAZIONI)



Appendix 3.

SMITHSONIAN ASTROPHYSICAL OBSERVATORY
M E M O R A N D U M

From: Dr. Michael R. Pearlman

To: For the Record

Subject: Status of the Italian Laser Program

Date: 18 June 1982

Franco Palutan from Telespazio met with us on June 7 to discuss the status of the laser relocation to Matera, Italy. We also discussed some of the details of network operations and data acquisition.

Weather data for the years 1979 and 1980 for Ginosa Marina which is within 10 miles of Matera was provided by Palutan. The cloud cover data is attached. It appears that there are three very good months (July, August and September) and three fair months (May, June and December) for optical observations. The other six months are marginal. Unfortunately, the clear season comes during the summer when night time hours are at a minimum. On the positive side, the weather pattern is common to most of Europe and the Mediterranean area so that all stations should be experiencing good weather at the same time thereby maximizing our opportunity for baseline measurements.

We have reviewed the building design. Several minor modifications were required, but these should be easily accommodated. Based on the current situation, building construction will not be underway until mid-August at the earliest. This projects equipment setup in January 1983 and operations in the April 1983 timeframe. This means that equipment will not be shipped until October 1982. In an attempt to expedite things at Matera, we will do as much of the upgrading modifications and testing here in Cambridge before the equipment is shipped.

Prof. Guerriero plans to visit SAO on June 24. At that time we will review the Working Level Agreement between SAO and CNR, and discuss the financial issues.

cc: A. Adelman, GSFC
T. Fischetti, NASA HQ
J. Gregory, SAO
E. Lilley, SAO
H. Penfield, SAO
D. Townley, NASA HQ

Appendix 4.
May 1982

Professor Luciano Guerriero
Director, National Space Plan
Consiglio Nacional delle
Richerche (CNR)
202, viale Regina Margherita
I 00198 Roma
ITALY

Dear Professor Guerriero:

Now that (1) NASA and the CNR have agreed to terms for the indefinite loan and operation of an SAO laser in Italy and (2) NASA, CNR, and SAO have agreed on a site at Matera, Italy all that remains is that SAO and CNR conclude a basis of understanding at the working level.

To carry out this program we suggest the following division of responsibilities:

SAO RESPONSIBILITIES

STATION SETUP

On a reimbursable basis (direct cost plus indirect cost from CNR, SAO will:

1. Pack and ship a fully operational laser ranging system to the agreed site.

2. Provide the latest field software in use with the other SAO lasers.

3. Provide the necessary manpower to set up the laser and upgrade the system as per the latest SAO modifications (already installed at Arequipa and Mt. Hopkins).

4. Provide manpower, on an interim basis as agreed, to train Italian personnel at the site and to assist in the transition to a fully operational station. It is anticipated that this will require a maximum of 2 man months after the laser is operational.

5. Provide on site training in Cambridge and at a field station for two CNR representatives.

STATION OPERATIONS

Within the constraints of NASA support SAO will, on a best efforts basis:

1. Provide on an operational basis orbital elements in the appropriate format for laser pointing predictions.

2. Provide routine data review and engineering/operations assessment reports on a timely basis.

3. Provide headquarters support in terms of scheduling, priorities, and network coordination.

4. Provide designs for any future hardware upgrades that are applied to the SAO lasers, providing hardware when requested on a reimbursable basis.

5. Provide any future software modifications and upgrades that are applied to the SAO lasers.

6. Provide repair and maintenance service on a reimbursable or trade basis as appropriate on hardware, components, systems, and subsystems.

7. Provide Field Engineering support on a reimbursable basis.

8. Provide reformatted final data from linc tape to industry compatible magnetic tape on a routine basis and/or provide the SAO software to perform the reformatting process.

CNR RESPONSIBILITIES

STATION SETUP

CNR will make its best effort to:

1. Provide a building design agreeable to SAO.

2. Prepare the site and building as necessary to accommodate the laser system.

3. Assume all direct costs for station setup items above.

4. Provide all necessary administrative assistance to SAO personnel entering and leaving Italy.

5. Provide sufficient manpower and local support and resources to set up the station.

CNR will make its best efforts to:

1. Operate the station as per the NASA-CNR agreement (specified in a letter from M. G. Finarelli to L. Guerriero dated November 24, 1981).

2. Make all quick-look and final data available to SAO on a punctual basis as agreed.

3. Provide operations and configuration control as per NASA Laser Tracking Network requirements.

It is intented that this agreement should be in consonence with and subordinate to the NASA-CNR agreement of 29 November 1981 with SAO acting on behalf of NASA.

It is understood that the ability of SAO and CNR to carryout their respective obligations is subject to availability of funds, and in the case of SAO, the concurrence of NASA.

SAO and CNR agree that, with respect to injury or damage to persons involved in operations undertaken pursuant to this agreement, neither SAO nor CNR shall make any claim with respect to injury or death of its own or its contractors' or its subcontractor's employees or damage to its own or its contractors' or its subcontractors' property caused by activities arising out of or connected with this project, whether such injury or damage arises through negligence or otherwise.

This agreement shall remain in force and effect from the date of it's execution for an indefinate period of time, however it may be terminated by SAO any any time by giving CNR a one hundred twenty (120) day advance written notice of termination.

IN WITNESS HEREOF, the Smithsonian Astrophysical Observatory and the Consiglio Nationale delle Ricerche have caused this Agreement to be signed and sealed in duplicate.

Very truly yours,

John G. Gregory
Deputy Director

APPENDIX 5

STUDY OF THE
TIME EVOLUTION OF THE LITHOSPHERE

Grant NAG 5-150

Semi-Annual Progress Report No.

For the period 1 September 1981 - 28 February 1982

Principal Investigator

Dr. Micheline C. Roufosse

Prepared for
National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

May 1982

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

NASA: SEMI-ANNUAL REPORT

In this work, we have interpreted the geoid heights derived from the GEOS-3 and SEASAT radar altimeters. The research is divided into two main parts:

-the interpretation of the short wavelengths (ranging from 60 to 300 km) contained in the geoid spectrum; these can be explained in terms of lithospheric properties

-the interpretation of the intermediate wavelengths (ranging from 200 to 2000 km); these yield information on the properties of the convective flow occurring in the earth's interior.

During the next reporting period, we intend to develop the two-dimensional filters necessary to reproduce the two-dimensional geoid. We shall also study the Azores area.

Short Wavelength Study

The lithosphere is considered as a thick elastic plate; as it moves away from the ridge nest where it has been created, it ages, cools and thickens and thus its mechanical properties evolve as the thickness increases. We can probe these changes by studying the response of the lithosphere to different loading situations. For that purpose, we need to know the age of the lithosphere as well as the time and conditions of loading. In previous reports, I have described results obtained from the interpretation of the GEOS-3 radar altimeter data along the Hawaiian-Emperor Seamount chain, the New England Seamounts, the Walvis Ridge and other chains of Seamounts. Conversely, the time

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and conditions of loading can be derived for a specific event by comparison with known situations. I have used the SEASAT radar altimeter data to explain the formation of the Rio Grande Rise which is located at the same latitude as the Walvis Ridge, on the Western side of the Mid-Atlantic Ridge. In a previous study performed over the Walvis Ridge, we have observed that the direction of that Ridge is incompatible with a fixed hot spot origin (see Figure 1). It is postulated that the Ridge has been formed in three main episodes by the same hot spot located at three different positions. The Eastern section was formed first by a hot spot located on the Mid-Atlantic Ridge. That hot spot then moved southward on the Mid-Atlantic Ridge and then caused the creation of the Central section of the Walvis Ridge. It finally moved toward its present location, Tristan da Cunha, off the Mid-Atlantic Ridge, and was responsible for the creation of the Western section of the Walvis Ridge.

We have thus encountered two different regimes of seamount formations: the first two segments were created on the Mid-Atlantic Ridge on zero age lithosphere and moved along with the plate to their present position. The last segment was created on young lithosphere. These two regimes give rise to different geoid signals as can be seen in Figures 2 and 3. The Seamounts formed on young lithosphere offer a much sharper signal than those formed on zero age lithosphere. We have used the thin elastic plate model to explain the geoid anomaly observed over the Western section of the Walvis Ridge. In order to explain the

geoid anomaly observed over the Eastern and Central sections of the Walvis Ridge, we have used the Airy model of crustal thickening.

The Rio Grande Rise developed west of the Mid-Atlantic Ridge at the same latitude as the Walvis Ridge. Figure 4 shows the SEASAT data selected for this work superposed on a sketch of the Rio Grande Rise. Figures 5 and 6 show a few satellite passes selected in that region: they all show a 4 meter deflection associated with the Ridge, superposed on a 10 to 12 meter broader geoid anomaly which can be explained only in terms of convective upwelling in the mantle. The 4 meter signal associated with the Rio Grande Rise resembles that observed across the Eastern and Central sections of the Walvis Ridge, thus suggesting a formation of the Rise, on the Mid-Atlantic Ridge, simultaneously with the Eastern and Central sections of the Walvis Ridge. A thin elastic plate model could not account for the magnitude and wavelength of the observed geoid anomaly and we have chosen instead an Airy type model. The results obtained suggest a crustal thickening of 25 to 30 km in that region (Figure 7).

Intermediate Wavelength

The geoid heights used in this study are derived from the GEOS-3 radar altimeter. We have applied to the data the atmospheric and oceanic corrections provided with the data set. We have further corrected the data for inaccuracies in orbit determination by removing a bias and a trend provided by

Dr. Rapp. We thus obtained a two-dimensional geoid of an overall accuracy of 60 cm. Because the geoid is dominated by large magnitude long wavelength anomalies, of no interest to us in this work, we have subtracted from the data a reference geoid, calculated with GEM7, up to degree and order 10. The residual geoid heights so obtained are then filtered using a Gaussian filter of half-width 100 km in order to smooth the data. These filtered values are then interpolated onto a square mesh and machine contoured. Figure 8 shows the smoothed residual geoid and Figure 9 represents the smoothed bathymetry. There is an obvious correlation between bathymetric features and geoid anomalies. These correlations fall into two categories:

1. Small geoid anomalies of the order of 2m, such as that observed over the ninety East Ridge. They can be explained totally in terms of lithospheric loading.

2. Large geoid anomalies, from 4 to 10m such as Kerguelen, South of Australia. These anomalies cannot be explained in terms of lithospheric loading; they are associated with convectively maintained density anomalies, below the lithosphere.

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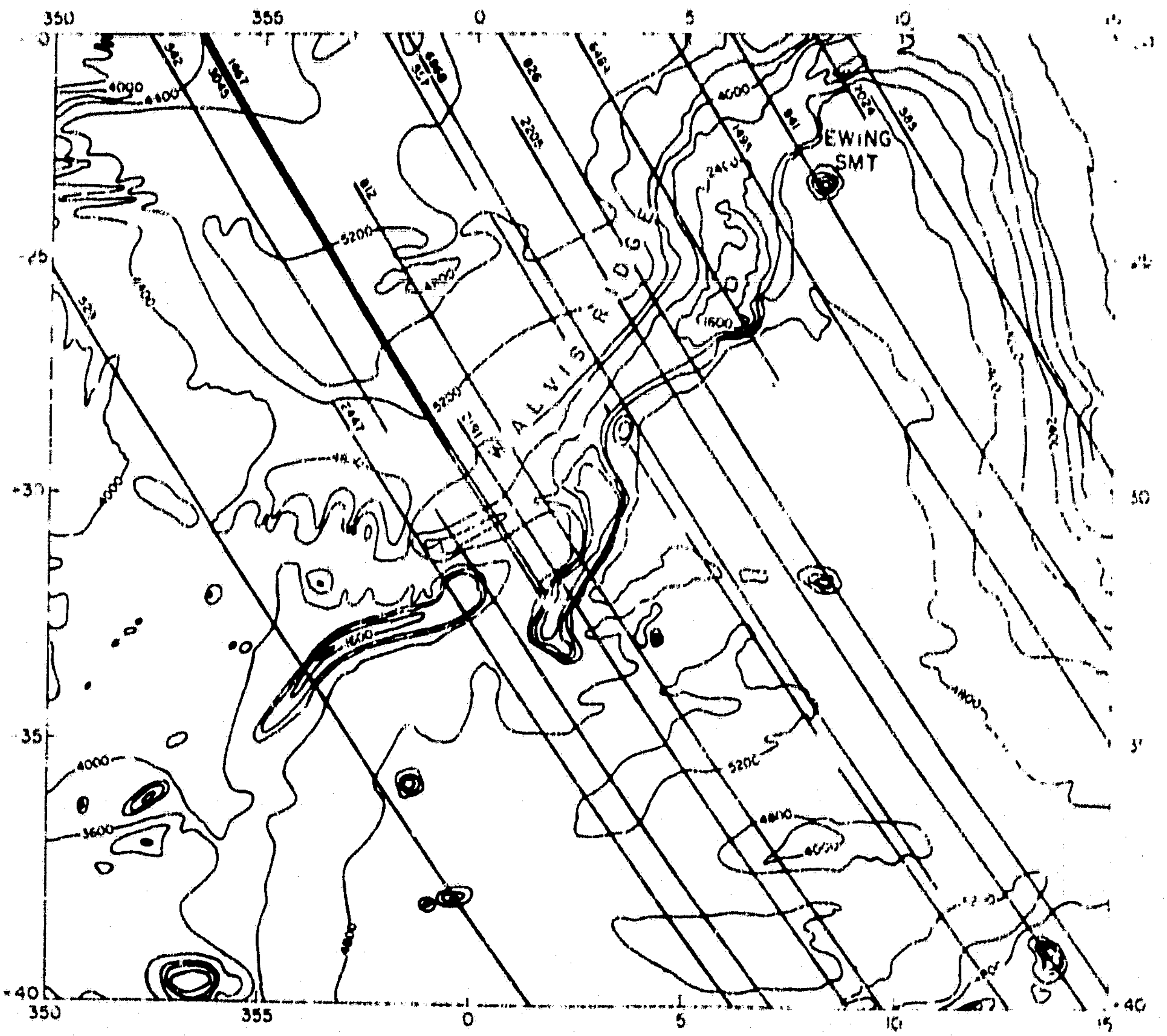

Figure 1 Bathymetry of the Walvis Ridge area and plot of the satellite passes selected over that region.

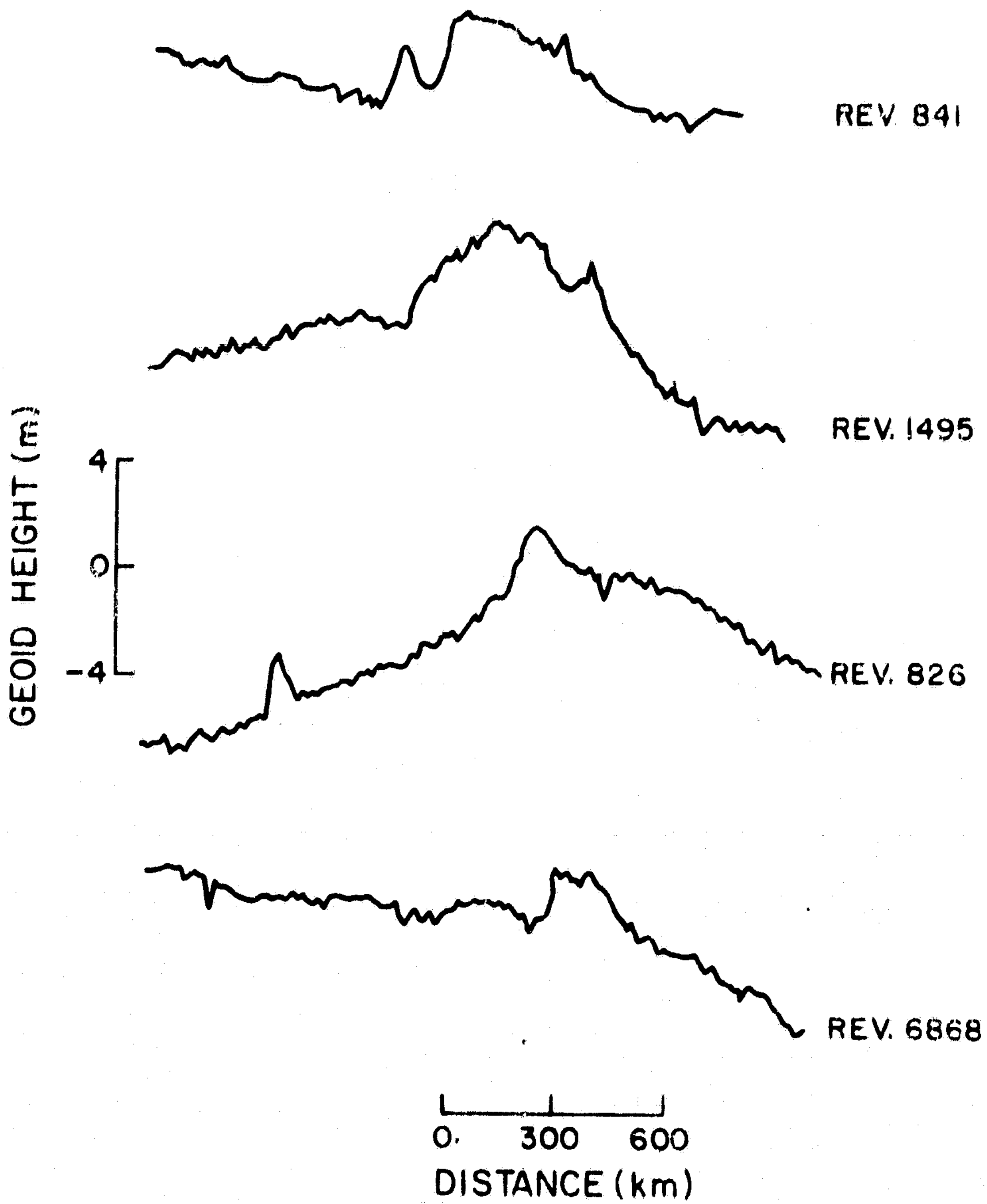

Figure 2. Four observed geoid profiles over the eastern and central sections of the Walvis Ridge, represented with respect to a reference geoid of degree and order 16.

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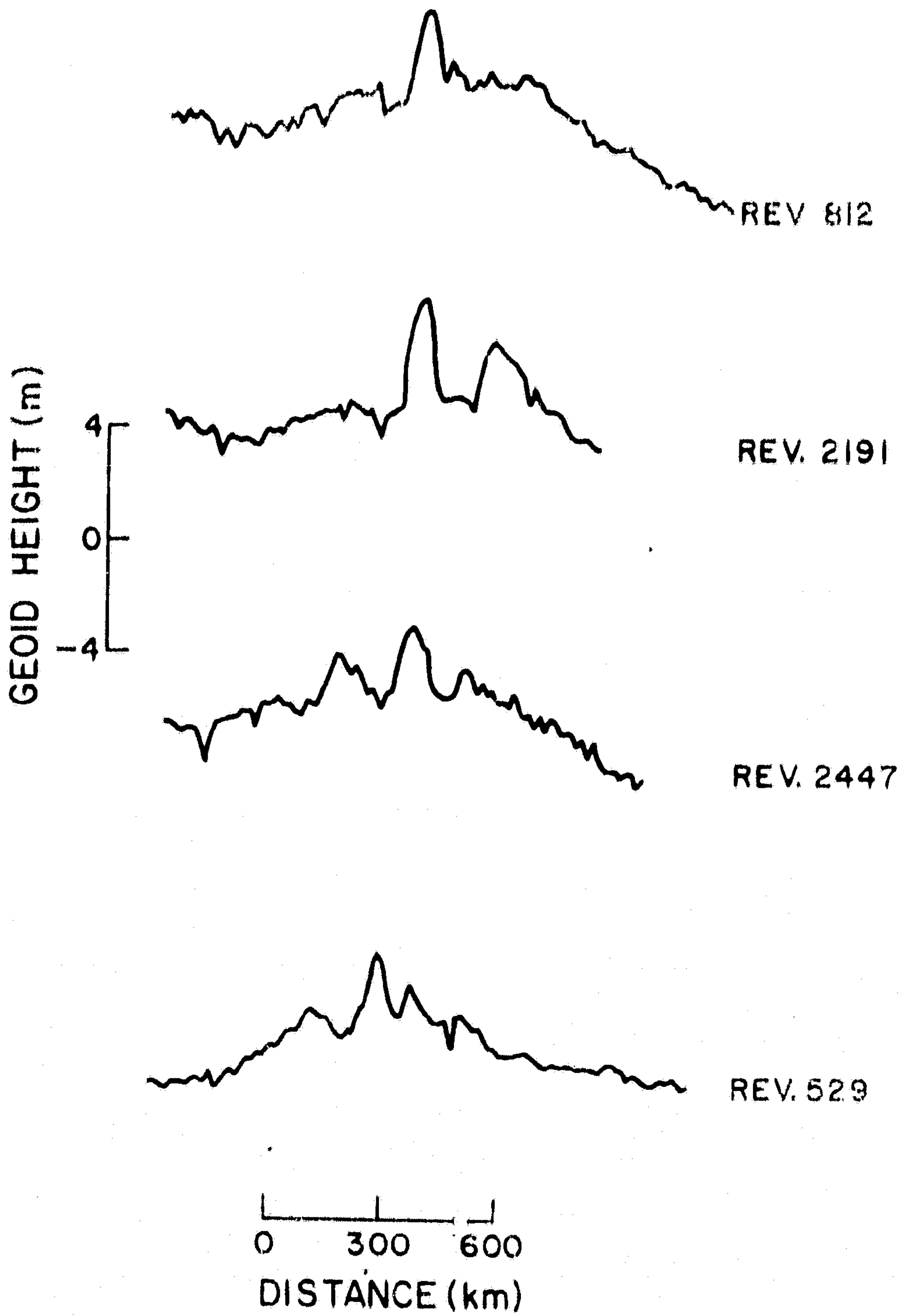

Figure 3. Four observed geoid profiles over the western section of the Walvis Ridge, represented with respect to a reference geoid of degree and order 16.

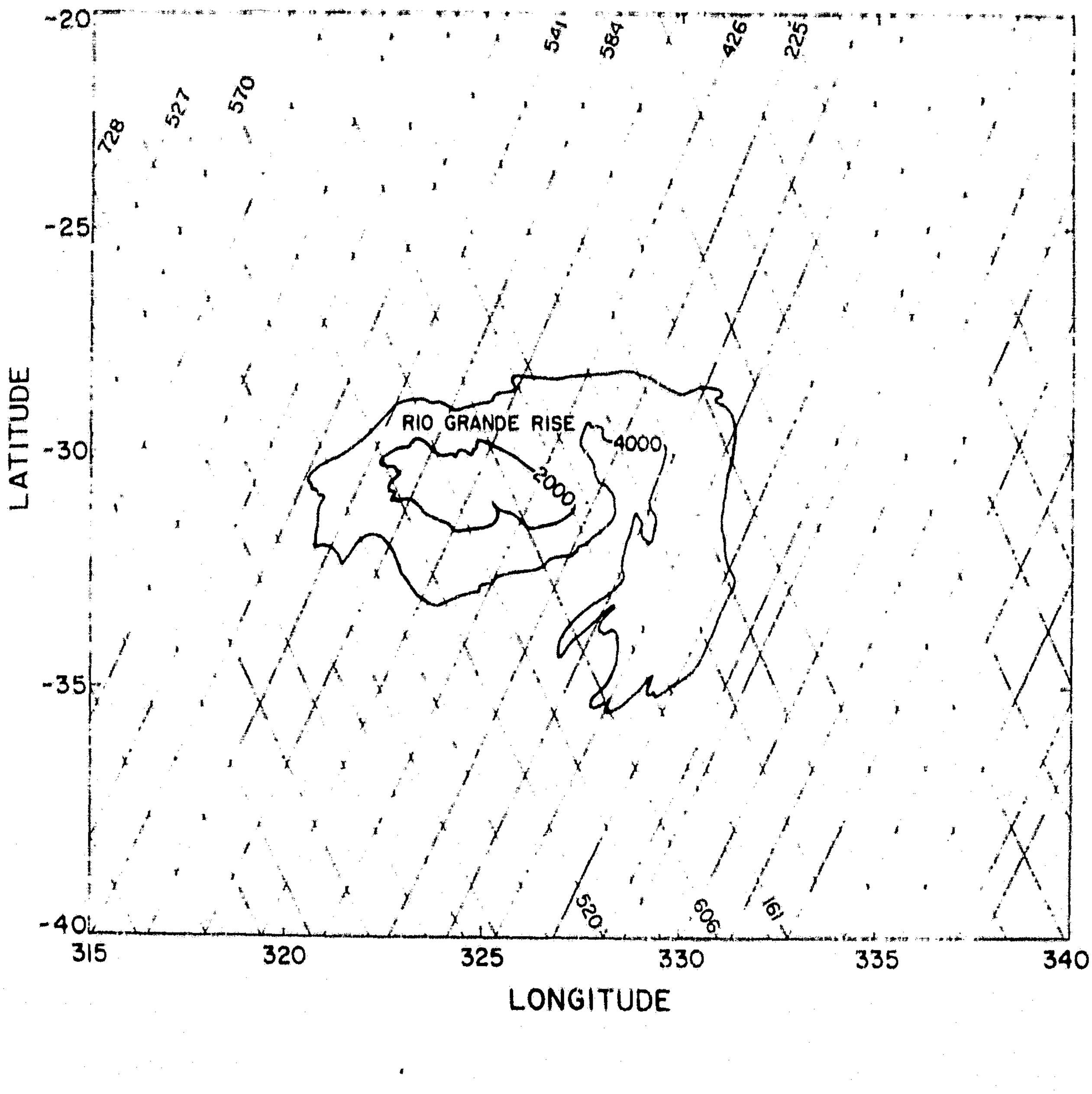

Figure 4. SEASAT radar altimeter coverage over the Rio Grande Rise

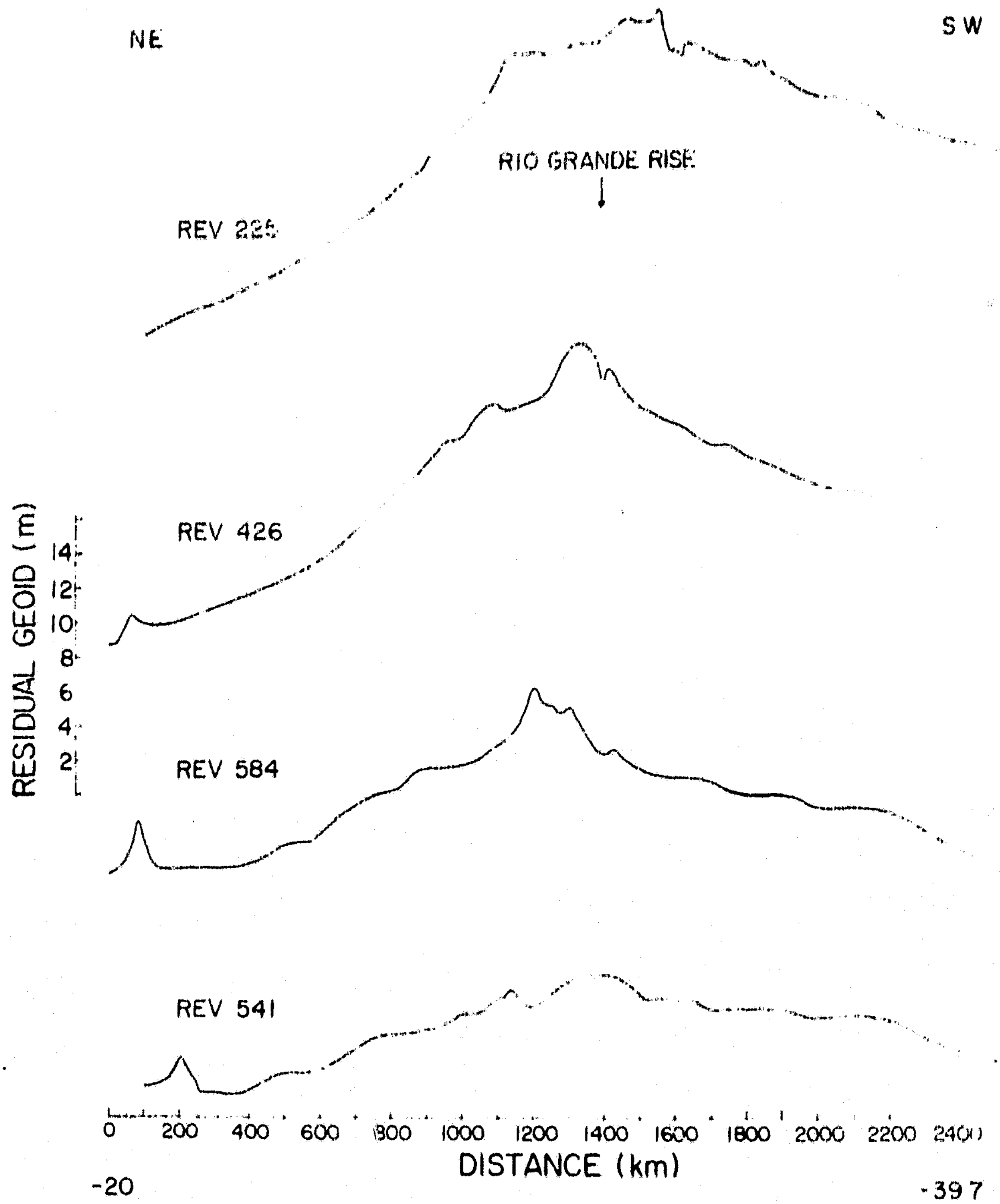

Figure 5. SEASAT radar altimeter profiles over the Grande Rise.

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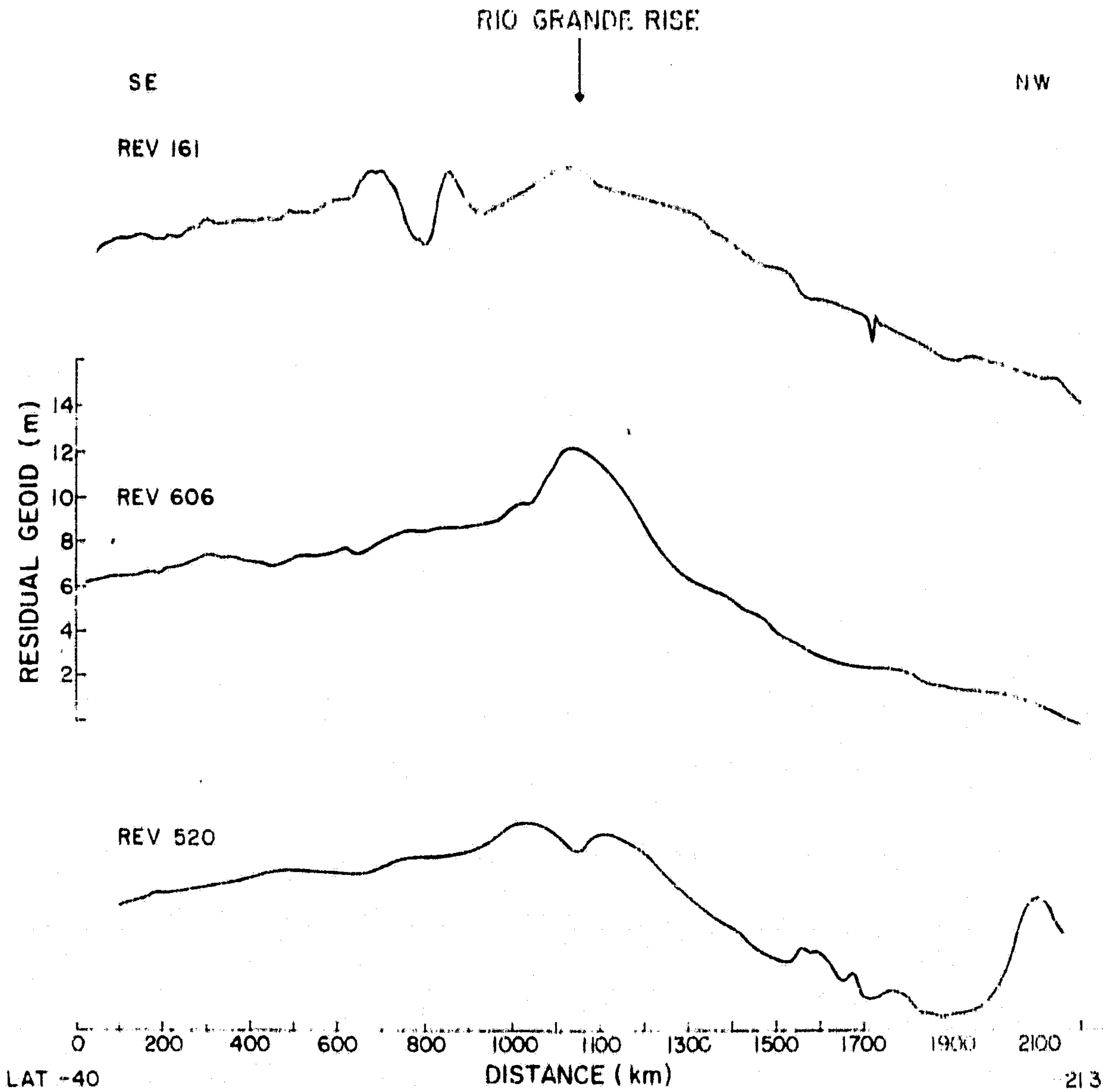

Figure 6. SEASAT radar altimeter profiles over the Rio Grande Rise

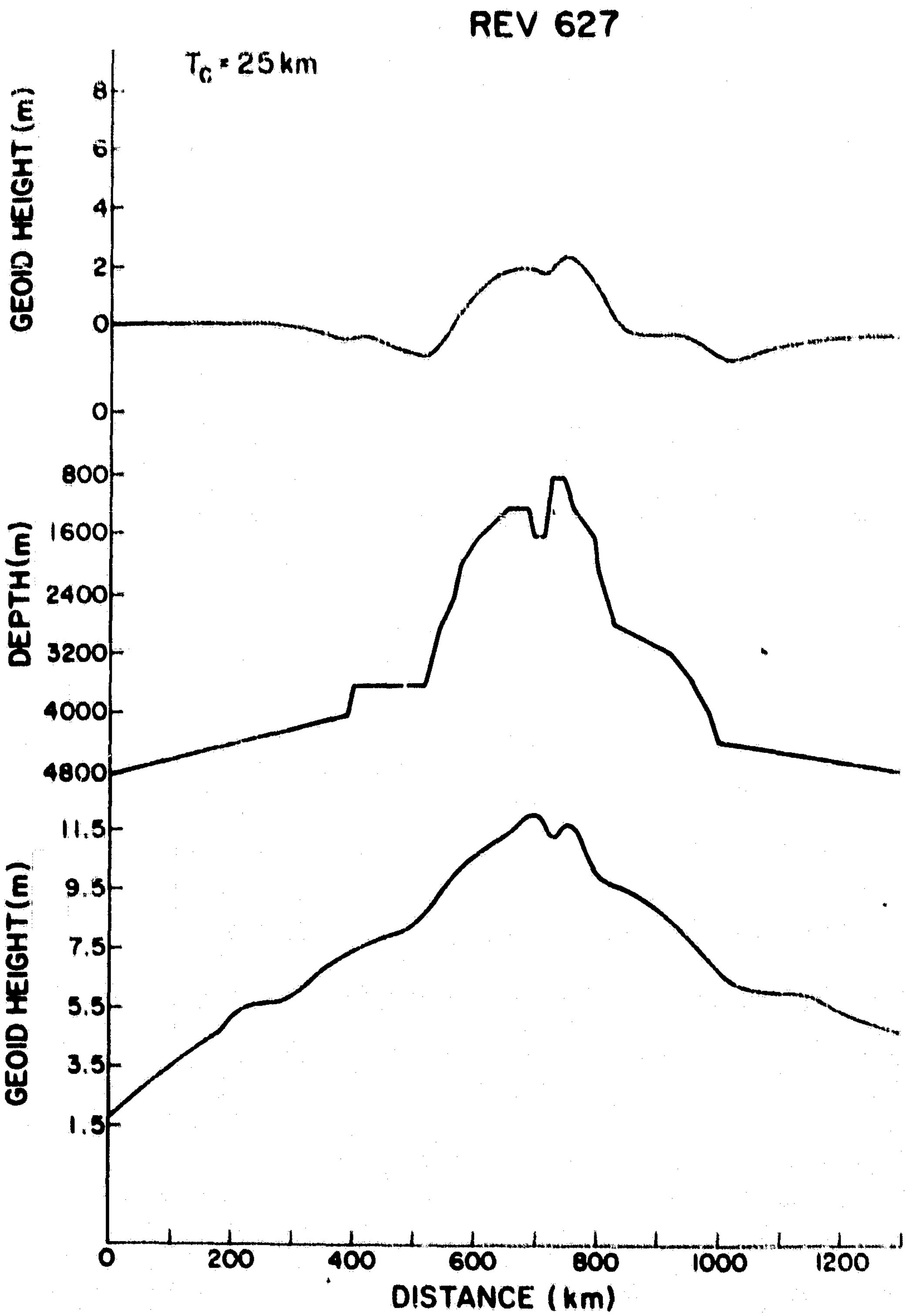

Figure 7. The bottom profile represents the observed geoid heights over the Rio Grande Rise, the intermediate profile represents the bathymetry and the top profile a theoretical geoid calculated from the Airy model with a crustal thickening of 25 km.

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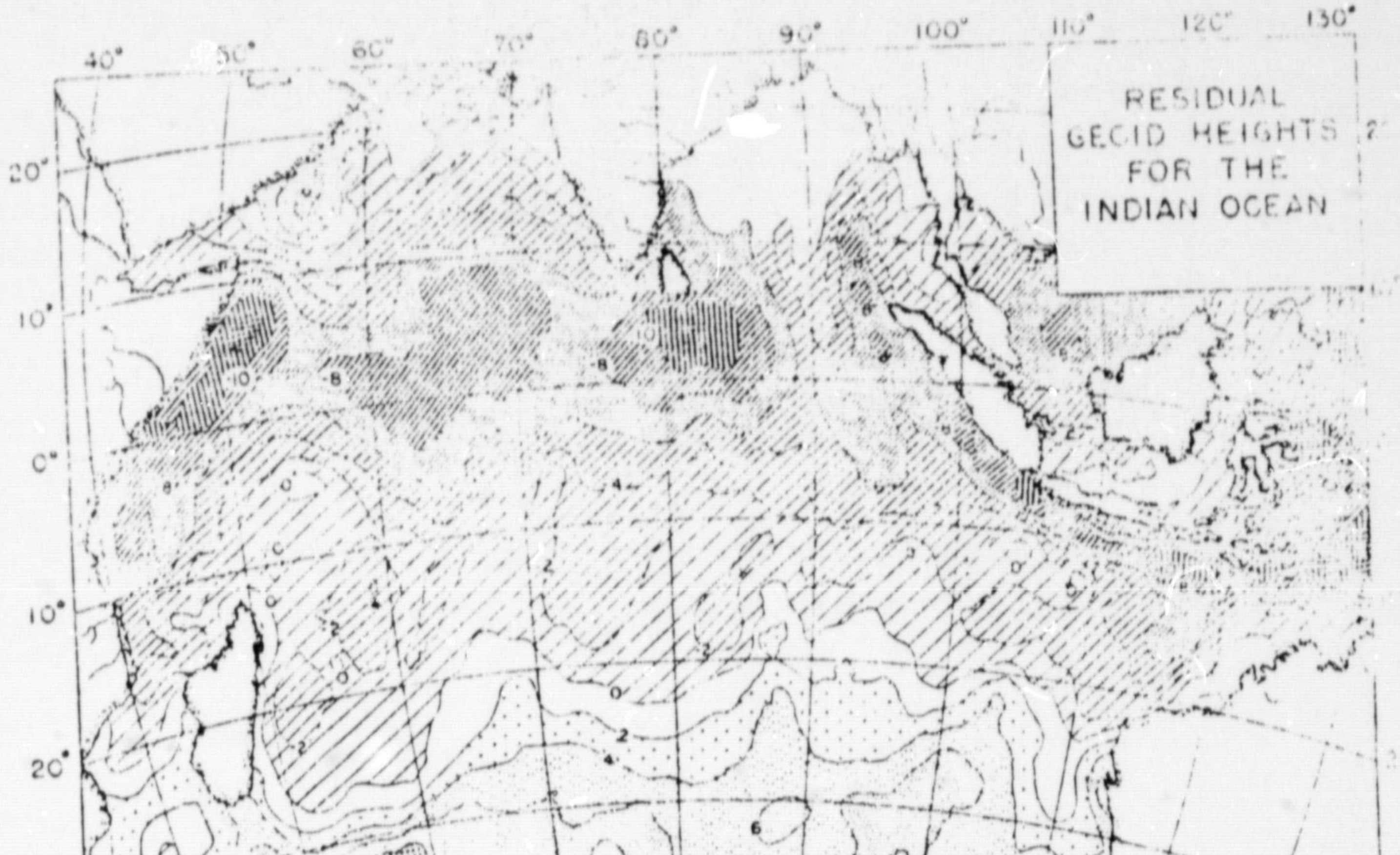

Figure 8. Residual geoid heights in the Indian Ocean.

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Figure 9. Smoothed bathymetry in the Indian Ocean.